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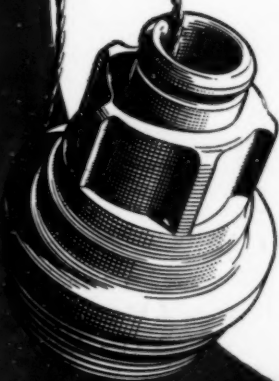
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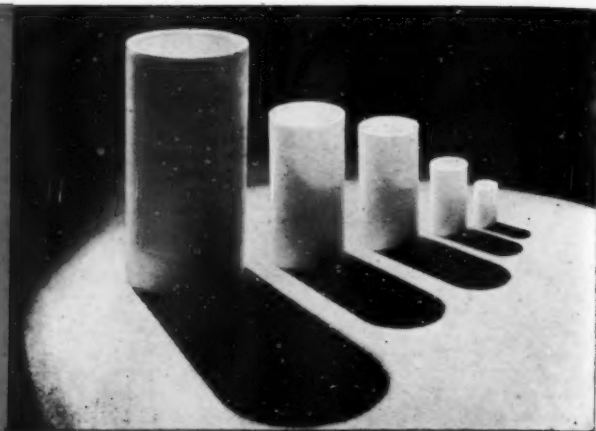
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The British Journal of Metals

(INCORPORATING THE METALLURGICAL ENGINEER)

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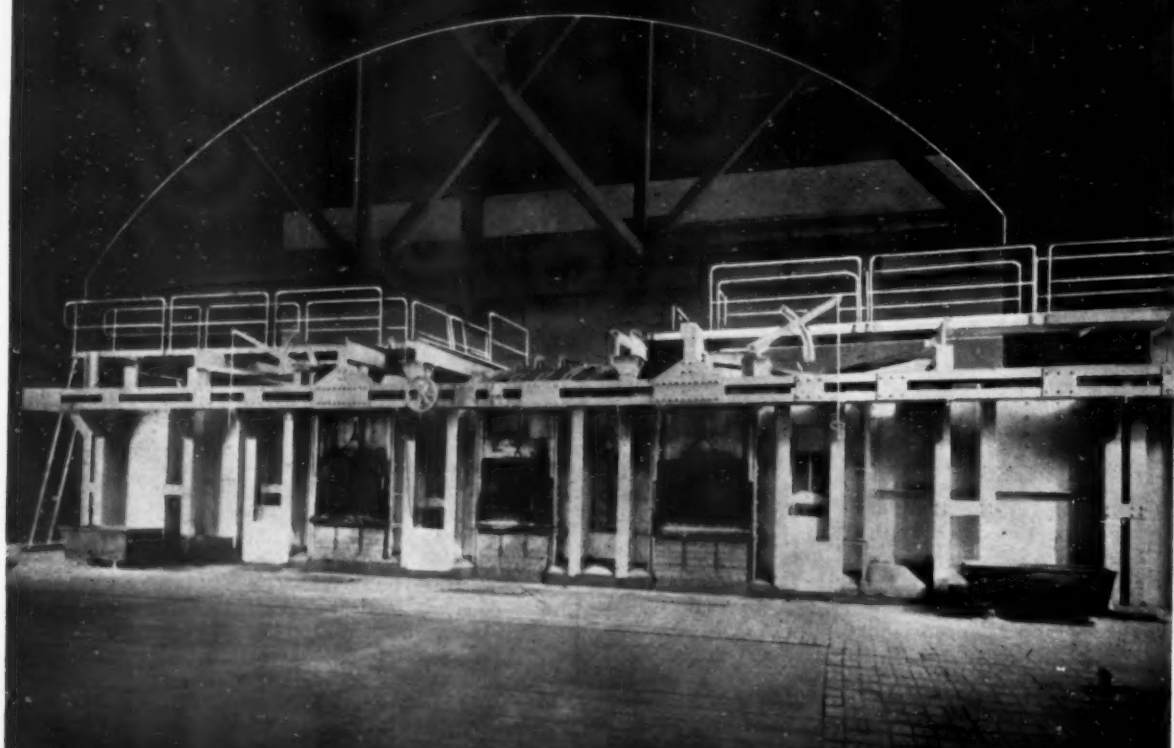
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METALLURGIA

THE BRITISH JOURNAL OF METALS.

INCORPORATING "THE METALLURGICAL ENGINEER."

OCTOBER 1947

Vol. XXXVI No. 216

Productivity—The Key

WE have been warned and exhorted by industrial and political leaders and by many others, who claim to be in touch with the problems that beset this country, that Britain faces an economic crisis of great magnitude and that greatly increased productivity for overseas markets is the only solution. Despite these warnings and exhortations, however, the gravity of the position seems to be entirely beyond the comprehension of the great mass of her people. It is difficult to understand why this should be so. The position has been stressed quite adequately that, with the rest of the world, Britain is suffering as a result of a very rapid acceleration of industrial tendencies which were developing before the war. That acceleration has been brought about by the war. Before the war the productivity of the United States was outstripping that of the rest of the world and it was becoming increasingly difficult for other countries to balance their payments to that country. The enormous increase in productivity in the United States during the war, coupled with the wholesale destruction of the means of production in Europe and the Far East, has enabled the United States to build up a huge surplus of exports over imports.

The difficulties arising from this want of balance were largely shelved during the period immediately following the war, partly by free supplies distributed by UNRRA and by dollar loans and credits from the United States and from Canada. These were of a temporary character designed to give breathing space and to permit the rest of the world to bring up its productivity in food, raw materials, and manufactured commodities to a position much nearer a balance, but the loans and credits were exhausted earlier than was expected, largely due to rises in prices, and together with the cessation of UNRRA supplies, an acute dollar shortage has resulted. We must, therefore, make a more urgent and comprehensive effort to balance our overseas payments than has yet been made and as rapidly as possible.

One thing we must decide is whether we want American aid. Many believe that we should not accept aid from America, that Empire sources can fill the gap in our food supplies caused by the exhaustion of our dollars. But Sir Stafford Cripps has given a warning that without fresh aid we face the prospect of a "descending spiral of depression" and those familiar with the position will not regard that as mere alarmism. We must maintain our food standard because of the effect of further cuts on the productivity of our people. Thus, however much we may deplore the need for assistance, it would be unwise to reject American aid if it is offered. We cannot sell our exports in the sterling area in sufficient volume and some form of American support for sterling would give us more scope for our products in the world's markets; it is of primary importance, however, that we increase our productivity.

The present lack of interest in what is a vital national problem is doubtless due, in no small measure, to the feeling that the average person in industry cannot do anything about the financial position of the country: there seems to be a sort of hopeless, helpless sense of futility that many feel about the warnings and exhortations, which must be eradicated. Much is, of course, being done in this country to redress the balance of payments and substantial cuts have been made in imports, while Sir Stafford Cripps seems to be meeting with some success in stepping up production for exports, although it is too early to determine whether the increase is likely to reach the target set. The objective is purposely of a very moderate character and well within the capacities of the industries concerned, especially if all in those industries regarded it as a personal obligation to do everything possible to achieve it. Warnings of further cuts in imports is an indication that Britain is still dipping steadily into her gold reserves. But cuts in imports must obviously be of a temporary character, it is on increased productivity that we must rely to restore equilibrium to the balance of payments.

On this question of productivity the performance of the iron and steel industry is especially noteworthy. The returns for September show that production, based on an annual rate, was only about 200,000 tons less than the target set for 1948. The performance of this industry and its management, in planning, production and development, hampered as it has been by prolonged uncertainty as to its future, is remarkable. Owing to the deepening of the economic crisis, which demands concentration on increased production of iron and steel, it is reported that the Government has decided to postpone nationalisation of this industry for a year. This decision will be welcomed by industrialists many of whom think that nationalisation of such a vital industry at this time might easily precipitate national disaster.

Although our national fortunes are impoverished and the outlook is grim, the conviction that we can save ourselves by our exertions will grow, and through our tribulation we may not only overcome our present difficulties but as a people and as individuals, restore our self respect. Our urgent need is increased productivity and it should not be necessary to devise incentives or bribes to stimulate the performance of obligations or service; the outcome of our tribulation may well effect a better conception of the relationship between work and its reward, which will restore a sense of dignity and responsibility to us as individuals. Certainly, if we are to maintain our existence on this densely populated island, there must, without any further delay, be a keen recognition by all of the hard fundamentals of our national economy. Not only must we re-assert British initiative, enterprise and adventure, but we must try to recapture the virtues of duty, honesty and self-discipline in order to perform, at all costs, our personal obligations and undertakings.

The Prague Sample Fair, 1947

FEW British metallurgists and production managers realise the diversity and quality of Czech machine tools and equipment, otherwise a bigger proportion of tools and equipment, not available from British manufacturers, would be obtained from Czechoslovakia rather than from other countries. Those who went to the Prague Fair will appreciate this expression of opinion. It was held on September 5th-14th and comprised nearly 3,500 stands spread over the old and new Fair grounds and the Exhibition building. This Fair bore visible signs of its international and export character: some fourteen foreign countries were represented either by official displays, or through representatives in the various branches of industry, while there must have been very few commercial countries not represented by buyers or important economic personalities.

Although glass products and furniture are Czech specialities, a large amount of industrial equipment was exhibited and it appeared to be of a high standard: a comparison of prices was not possible, but it is probable that the cost of the equipment available would be appreciably cheaper than equivalent equipment Britain obtains from other countries. On the machine tools and equipment side, the foreign section was small, the only interests being a selection of large lathes and power tools, which filled the Polish section, and a few machines and three types of motor cars in the Russian section.

The amount and variety of sheet metal, tube and other sections, wire, castings and other semi-finished ferrous and non-ferrous metal products and fabricated metal parts exhibited, were relatively small, but two large halls were filled with various types and sizes of lathes, power drills, bandsaws, automatic machinery and welding equipment. All these Czech products seemed to be well made and finished: many lathes and some resistance welding equipment were demonstrated at frequent intervals or by request. A 200 kw. high frequency generator for operating an induction furnace attracted much attention. Among the exhibits were carbide tipped and also diamond tools. On the testing side, there was apparatus for the detection of internal flaws, including ultrasonic and X-ray methods; and the Poldi hardness tester—in some respects a miniature Vickers hardness testing machine—was on view, as also was an Ericksen lacquer and paint adhesion tester for metal strips.

The exhibits were of such a character and so extensive that criticism of the Czech products is not possible, but it is suggested that those with particular interests in the fields covered by the exhibits, should consider visiting the next sample Fair to be held in Prague. The journey to visit the recent Fair by the writer was made by air and the time between aerodromes occupied 3½ hours, at a cost of £33 return—equivalent to first class rail travel, but without the disadvantages. On land and water, the journey occupies about 38 hours, mostly in a train, and there are six sets of customs and inspections encountered en route, the 20 hours' journey across Germany being without food or water.

A knowledge of the Czechoslovak language is not essential, many Czechs speak English, some speak French, while almost everyone speaks German. The

Czech Consulate, through their Chamber of Commerce, is very helpful in making appropriate contacts. It is also of interest that ample food is available and Pilsen beer abounds in the cafes throughout the city.

The main purpose of this Fair, as pointed out by Dr. Hubert Ripka, the Czechoslovak Minister of Foreign Trade, at the Opening Ceremony, was to increase foreign trade. Speaking of the productive abilities of the country, he said he regarded the Fair as an interesting comparison of the results of nationalised and of private industry, a principle which had been deliberately retained in Czech national economy to foster competition, which they regard as an important factor, because it acts as an insurance both against slackness in work and against the bureaucratisation of industrial activities. Continuing, Dr. Hubert said that high quality at low prices is to-day an essential condition for success in international competition, which is becoming continually sharper. The world's markets will only accept goods which are worthy of the world's standards, so that foreign trade compels Czech producers to turn out goods and appliances of true world quality. This means that such efforts must be made that, even in the most distant markets, Czech products may successfully compete, both in quality and in price, and also as regards an acceptable period and conditions of delivery which must be strictly adhered to.

The development of the world's economy must be regarded, as Dr. Hubert pointed out, entirely realistically without either distorting optimism or damaging pessimism. The shortage of the dollar exchange is becoming a world problem, and is, of course, also affecting the export interests of the United States: but a deficit dollar balance is by no means a special problem of Czechoslovakia alone. During this year, the United States and Great Britain have been Czechoslovakia's greatest suppliers, especially as regards imports of industrial materials. To ensure a continuance of these supplies necessitates exports to the dollar and sterling areas.

Czechoslovakia and Great Britain, it will be noted, have much in common and much that the Minister for Foreign Trade said could be applied with equal force to British manufacturers and their products for overseas markets.

Mr. Robert C. Stanley Honoured

THE KING has awarded His Majesty's Medal for Services in the Cause of Freedom to Mr. Robert C. Stanley, in recognition of his valuable services to the Allies.

Mr. Stanley is Chairman and President of the International Nickel Company of Canada, Limited, and, in over 40 years' of service, has played a major part in the development of this important Canadian industry. He has been President of this Company since 1922 and, in addition, Chairman since 1937.

Besides his valuable work in the industrial sphere, Mr. Stanley was an active member of the British War Relief Society in America, during the war, for which he collected over a quarter of a million dollars. He recently returned to New York, on the completion of his first post-war visit to this country, where he spent six weeks studying conditions here, his visit being primarily concerned with the activities of The Mond Nickel Company in this country.

The Structure of Hard Chromium Deposits on Steel

By H. J. Goldschmidt, M.Sc., A.Inst.P.

The B.S.A. Group Research Centre, Sheffield.

Chromium plated layers on steel of great hardness and wear resistance ("hard chrome") have been investigated by X-ray analysis, and the structural conditions which are associated with high quality have been determined. It is found that the base metal plays a vital part and that the structure of the interface between it and the deposit largely decides the properties of the plating. In good hard chromium plate, a metastable linkage has taken place between the lattices of the ferritic steel matrix and the depositing chromium, which does not correspond to interdiffusion of the metal atoms, but is facilitated by hydrogen acting as a "linking agent." In poor quality plating there was no such linkage, the Fe and Cr lattices being entirely separate. The structure changes, on annealing the samples at temperatures up to 1,000° C., are followed in some detail, and three classes of occluded hydrogen can be distinguished, according to the firmness of binding in the lattice. The effect of external friction (wearing action) on the plating structure is found to be essentially different in the poor and good quality types. A number of subsidiary phenomena are observed and discussed.

Introduction

HARD electrolytic chromium deposits on steel have, in recent years, become of considerable practical importance in components in which hard, bright and wear-resisting surfaces are required. The present investigation arose out of the following problem presented for X-ray analysis. Of two apparently similar hard chromium-plated piston tubes, which had to withstand a long-time stroking action in service, one had passed a severe stroking test excellently and without signs of wear, while the other had suffered considerable abrasion after a short time. The object was to observe whether any structural difference could be detected. The information gained from this investigation is believed to be of interest well beyond the above special problem, because it reveals the structure of the interface and the manner of the binding of the chromium with the steel base. The structure of the base metal is found to have considerable influence, a fact which has often been disputed or neglected in previous investigations. Methods which detach the plating from the base, for instance by dissolving the latter, may therefore give rise to misleading results.

Previous Investigations

Several structure examinations on chromium plating have been carried out in the past, notably those by W. A. Wood^{1,2,3}, Hume-Rothery and Wyllie,⁴ Bozorth,⁵ Promisel⁶ and others. One of the earliest investigations is that of Bradley and Ollard,⁷ who found the occurrence of a hexagonal modification of electro-plated chromium as against the usual body-centred cubic form. This form, the existence of which was first denied⁸ and later confirmed, for instance by Sasaki and Sekito,⁹ and by Wood, appears however, only at high current densities and according to Wright, Hirst and Riley¹⁰ only when reducing agents were added to the bath and in the presence of a certain minimum concentration (18%)

of trivalent chromium. The cubic form is the one commonly occurring, and it is with this form that the present investigation is concerned. W. A. Wood established a close correlation between X-ray line broadening and hardness in the sense that increased hardness is generally associated with increased line width. According to Wood's interpretation, small particle size is the chief cause of this broadening which, in the case of bright deposits, corresponds to a crystallite size of the order of 10^{-6} to 10^{-7} cm. Levy and Tabot¹¹ share this view, but the weight of evidence goes in favour of the existence of internal stresses as a predominant cause of line-broadening in electro-plated layers (Promisel and others^{3,12,13}). Hume-Rothery and Wyllie's mechanical stress determinations support the lattice strain theory, but the long-standing controversy between the two schools of "stress" and "particle size" interpretation is by no means settled in the case of electro-deposits. In the writer's view, however, the two theories can well be reconciled in many cases, and Wright, Hirst and Riley¹⁰ take the view that both factors participate. A third factor which certainly enters into the problem is the occlusion of hydrogen in the metallic lattice, which in itself causes fluctuations in composition on an atomic scale, and therefore lattice distortion. Wood interpreted irregular intensities as the effect of particle shape as well as differences in size, but later seems to have abandoned this view in favour of that of preferred orientation. Glocker and Kaupp¹⁴ first established the existence of a pronounced fibre structure of chromium deposits in which the [111] axis, and, under certain bath conditions, the [211] axis, is normal to the cathode surface, i.e., parallel to the lines of current flow. According to Hotherhall's¹⁵ microscopic work, the crystals of the plated metal are influenced by those of the base metal and, under certain electrolytic bath conditions, can be made to grow in continuation to those of the base metal. Ordinarily, however, the preferred orientation of the deposit is independent of the base metal and primarily governed by electrolytic factors. Arkharow¹⁶ claimed a [111] orientation for

1 W. A. Wood. *Phil. Mag.*, **12** (1931), 853.

2 W. A. Wood. *Proc. Phys. Soc.*, **43** (1931), 138.

3 W. A. Wood. *Phil. Mag.*, **7**, **23** (1937), 984.

4 Hume-Rothery and Wyllie. *Proc. Roy. Soc. A*, **161** (1937), 331.

5 Bozorth. *Phys. Rev.*, **23** (1925), 390.

6 Promisel. *Metal Industry*, **3** (1933), 437.

7 Bradley and Ollard. *Nature*, **117** (1926), 123.

8 F. Sillers. *Trans. Amer. Electrochem. Soc.*, **52** (1927), 301.

9 K. Sasaki and S. Sekito. *Jnl. Soc. Chem. Ind., Japan*, (Suppl.), **33**, (1930), 482.B.

10 L. Wright, H. Hirst and J. Riley. *Trans. Faraday Soc.*, **31** (1935), 1253.

11 G. R. Levi and M. Tabot. *Atti. Accad. Lincei*, **6**, **17**, (1933), 647.

12 McKeehan. *Phys. Rev.*, **21** (1923), 334.

13 Greaves. *Metallurgist*, **25** (1925), 141.

14 Glocker and Kaupp. *Zell. Phys.*, **24** (1924), 121.

15 Hotherhall. *Trans. Faraday Soc.*, **31** (1935), 1242.

16 Arkharow. *Tech. Physics U.S.S.R.*, **3**, No. 12 (1936), 1072.

bright and a [100] for matt deposits. One of the most important and comprehensive investigations of this field is that of Hume-Rothery and Wyllie,⁴ who showed a clear correlation between current density and temperature of deposition on the one hand, and appearance, hardness and internal stress on the other. These authors have, however, attributed the hardness solely to the preferred orientation of the chromium layer and did not study the effect of the base metal in detail. It is hoped to show, however, that the structure of the steel base can be very important.

On reviewing the literature, it is noted that generally the authors' X-ray photographs revealed only the pattern of the chromium plate, and not that of the base metal. The reason is probably that either the thicknesses of their coatings were too considerable to permit transmission, or that unknowingly the lattice linkage with the steel base, which will be described below, had also occurred. It was perhaps an advantage in the present work that the available samples had a chromium plating sufficiently thin (of the order of 0.0001 in.) to reveal the base metal reflections, as well as those of the chromium.

PRESENT INVESTIGATION Experimental

The actual samples examined were cut from chromium-plated piston tubes of a hydraulic undercarriage gear, which had to resist in use a long-time stroking action by a plastic-impregnated canvas seal without appreciable wear. One sample was received in the unused state; another one after a severe stroking test to which it had stood up well without signs of scoring. Two corresponding samples, which had shown very poor wear resistance, were examined. For reasons explained below, portions of the two non-stroked samples were further subjected to a series of annealing treatments at 150°, 300°, 400°, 500°, 600°, 700°, 800°, 900° and 1,000°C., and subjected to X-ray analysis.

Vickers hardness tests on the original "wear resisting" and "easily worn" samples were carried out directly on the plated surface, using a very light load, viz., 20 gm.*

This gave reproducible results, indicating that the plate of the badly wearing sample was considerably softer than that of the resistant one. The following optical readings are given in the absence of a conversion chart for a 20 gm. load, and may serve as a measure.

Sample	Optical Readings (Vickers Hardness Machine)
Wear resisting	33-34
Easily worn	53-54

Although it is appreciated that hardness and wear resistance are two properties which do not necessarily go in parallel, this appears to be true in this case, and in the following the descriptions "good" and "bad" samples are meant to cover both properties.

The steel base metal was of the following composition in both samples (weight per cent.): C 0.22, Mn 0.45, Si 0.10, Cr 0.015, S 0.021, P 0.018, Ni nil.

Fig. 1 shows the type of X-ray photograph obtained from chromium plating on steel. Of the two lines observed, the outer one is due to the chromium layer, the inner one to the ferritic (or martensitic) matrix of the underlying steel base. Both correspond to plane [211] of the body-centred cubic structure. Iron has the smaller atom than chromium, the two unit cube edges

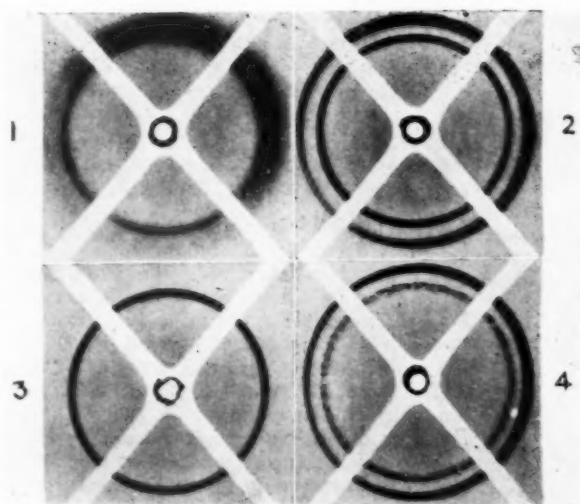


Fig. 1.—Representative back-reflection photographs from chromium plating on steel.

being 2.8607 kX for pure iron and 2.8787 kX for pure chromium (viz., 0.63% difference). The radiation used was chromium K α , which is found particularly suitable for chromium deposits because it gives comparatively low absorption of the iron reflection by the chromium coating for the existing plating thicknesses. A method will be mentioned later in which this absorption is made use of to measure the plating thicknesses.

The possible information which can be obtained from any one photograph is as follows:—

- (1) The average lattice spacing of the chromium layer.
- (2) The lattice spacing of the steel base.

The reason for any variations in lattice parameter is not diffusion between iron and chromium, although the iron-chromium system in equilibrium is one of complete solid solubility (excepting the sigma-phase). No such diffusion of metal atoms occurs during plating, as will be shown presently. The spacing differences are rather due to lattice strains, i.e., macro-strains as against the micro-strains giving line broadening, and, almost more important, due to hydrogen in solution. In practice, the lattice constants of iron and chromium were measured accurately by using gold as calibrating material. The K α doublet [222] of gold appears in addition to line [211] of chromium and to line [211] of iron. Since the corresponding inter-planar spacings are $d = 1.1754$ kX for gold and 1.1750 kX for pure chromium, the gold line falls very close to that of chromium, and provides a highly sensitive gauge for any variations in chromium parameter as well as in that of iron.

- (3) The lattice distortion of the chromium layer.
- (4) The lattice distortion of the steel base.

The term "lattice distortion" is used advisedly to describe the cause of line broadening, because, in principle, it may have been produced by (a) lattice stresses, (b) the occlusion of hydrogen during plating, (c) (in the case of the steel) the presence of martensite as against ferrite, and (d) partial interdiffusion of iron and chromium. Small crystallite size is a further possible cause of line broadening.

- (5) Preferred orientation of the chromium layer. This manifests itself by the non-uniform circumferential

* The author is indebted to Dr. W. Steven for these data.

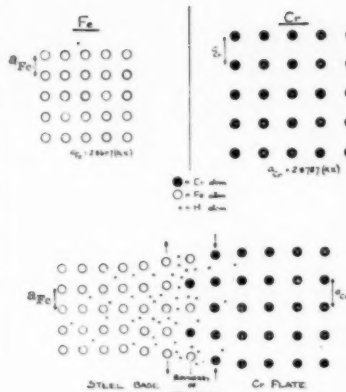
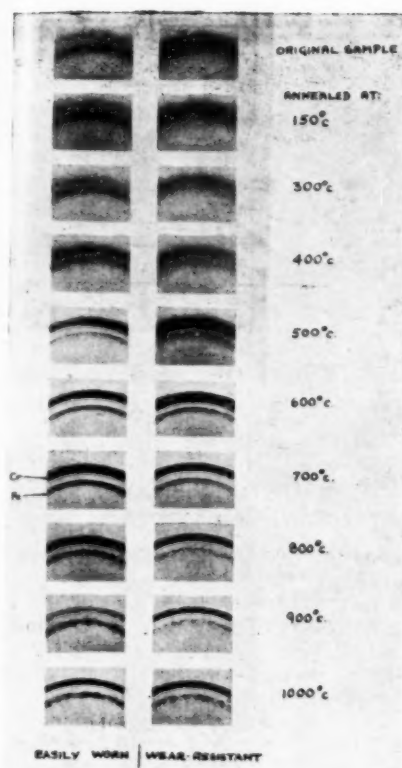


Fig. 3.—Diagram illustrating lattice linkage.

Fig. 2.—Effect of heat-treatment on two-chromium-plated samples. Sections from X-ray photographs showing reflections [211] of chromium-plate and steel base.

distribution of intensity along the chromium line (fibre diagram). This may be seen in pictures 1, 2 and 4 in Fig. 1, and, as mentioned, is due to the fact that the [111], sometimes the [211], direction tends to orient itself parallel to the lines of current flow in the bath. It may be noted that *only* the chromium lattice shows preferred orientation while the steel shows completely random orientation. It may therefore, be concluded that the direction of growth of chromium has in this case been governed largely by electrolytic conditions.

(6) Crystallite size. Differences in crystallinity are obvious from the spotty or continuous appearance of the lines. The crystal size of the chromium layer is in all cases well below 10^{-3} cm. The steel had recrystallised on annealing above 700°C ., giving an average size of the order of 10^{-3} to 10^{-2} cm.

(7) Thickness of the chromium layer. This can be determined by observing the reduction in intensity of the iron line due to the absorption of the over-lying chromium. Illustrations 2 and 3 of Fig. 1 illustrate this point. They were taken from the same sample with and without the chromium layer, and by photometry of the iron line it is possible to calculate the chromium thickness.

All the films were photometered in order to obtain a quantitative expression of line width for the Fe and Cr halos. On evaluation it was found, however, that in the case of diffuse lines, particularly where the photometer-curves for Fe and Cr overlapped, the consistency obtained by visual estimation of line width was more satisfactory than that derived by photometry.

A section from the X-ray photographs is reproduced in Fig. 2, a direct inspection of which may best serve to illustrate the differences in question. The results on line width and lattice dimensions are shown graphically in Figs. 4, 5 and 6.

RESULTS AND DISCUSSION

1. Structure of the Original Chromium Plate

A photograph taken from the original high-quality hard chromium plate shows instead of the two lines of iron and chromium a single line corresponding to an average lattice spacing and a point of maximum intensity at a position *between* that of iron and chromium. That this is not due to actual diffusion between the

two metals can easily be proved by annealing, when the two lines become completely resolved. The photographs in Fig. 2 show the effect of annealing the chromium-plated sample at the series of temperatures from 150°C . to $1,000^{\circ}\text{C}$. from which it may be seen how the single line becomes gradually resolved into two separate lines, corresponding to those of ferrite and chromium.

The reason for this merging of lines in the original sample is that a linkage has taken place between the lattice of the deposited chromium and that of the steel matrix. This union of lattices is not one of equilibrium but is meta-stable and does not involve interdiffusion of the two metals. There seem to exist certain conditions in the electrolytic bath, such as definite deposition temperatures, current densities or bath compositions, under which the formation of such a single metastable lattice of iron and chromium is encouraged. The theory is that a junction between iron and chromium is made possible by hydrogen acting as a "linking" agent. In the electrolytic bath considerable quantities of hydrogen are naturally liberated. Normally, hydrogen expands the chromium structure, as exemplified by the annealed samples, but in this case some of the gas has been dissolved in the ferrite or martensite lattice of the steel already *before* any appreciable amount of chromium had time to deposit. The occluded hydrogen expands the steel lattice to a size favourable for the formation of a link with the chromium subsequently deposited. After this lattice linkage has taken place in the bath, the ferrite finds itself with lattice dimensions unnaturally large and the chromium with dimensions unnaturally small, so that after the plating process is finished the tendency will be for each metal to adopt its normal unit cell size, and for the ferrite to eject its hydrogen. Nevertheless, the two lattices preserve their metastable unity so that very considerable strains are set up, involving compressive stresses parallel to the surface in chromium, tensile ones in the steel. It is considered that these enforced lattice strains are an essential factor giving rise to the hardness of the chromium plate in this condition. An excessive outside frictional force such as that due to the stroking action can, however, bring about a gradual breakdown of this lattice unity, as will be described below.

A "poor quality" chromium-plated sample in

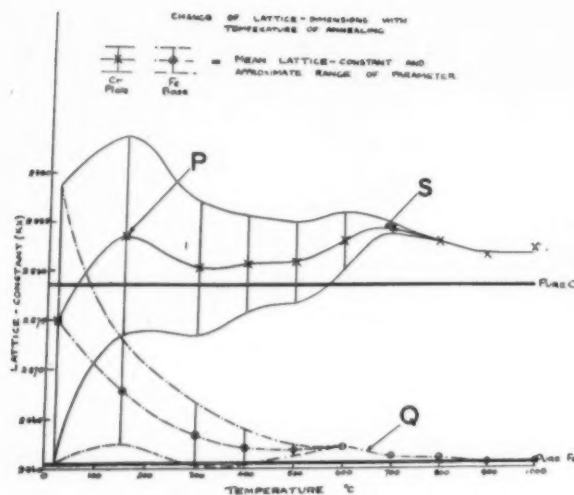


Fig. 4.—Hard chromium plating: high quality type.

contrast, showed on X-ray examination the iron and chromium lines to be entirely separate and of only moderate distortion, which verifies that the production of the linkage between base and plating is important. This may be seen in the left-hand column of Fig. 2 and from Table I.

TABLE I
MEAN LATTICE CONSTANT AND APPROXIMATE FLUCTUATIONS (FROM LINE WIDTH) IN ORIGINAL AND STROKED SAMPLES (KX).

Quality	Non-Stroked				After Stroking			
	Mean Spacing		Range of Spacing		Mean Spacing		Range of Spacing	
	Cr-plate	Fe-base	Cr-plate	Fe-base	Cr-plate	Fe-base	Cr-plate	Fe-base
Wear-resistant	2.873		0.028		2.8855	2.8645	0.018	0.007
Easily worn	2.885	2.8625	0.013	0.0065	2.8825	2.8620	0.015	0.012

Fig. 3 shows a schematic representation of the process on an atomic scale. The iron and chromium lattices of different cube edges are given separately on top; in the lower figure they are enabled to link up by hydrogen migrating into the iron and expanding the unit cell to a size favourable to form a single lattice of the chromium and a highly-strained boundary zone.

2. Effect of Annealing

The lattice dimensions obtained by annealing the high-quality sample at different temperatures are shown in Fig. 4. The single line of the original hard chromium sample becomes resolved into two on annealing at 150°C., though still very diffuse. The mean chromium value rises immediately above that of the pure metal, and stays above it at all subsequent temperatures, because hydrogen in itself expands the chromium lattice, and it was only the linkage with the steel which had enforced a lower spacing at the beginning. There appear two significant maxima in chromium spacing at P (150°C.) and at S (700°C. approx.). The relief of lattice strain on annealing is associated with the evolution of hydrogen, and the maximum P probably indicates the transit through the chromium layer of hydrogen previously dissolved in the steel base. At 300°C. this hydrogen has apparently escaped to the

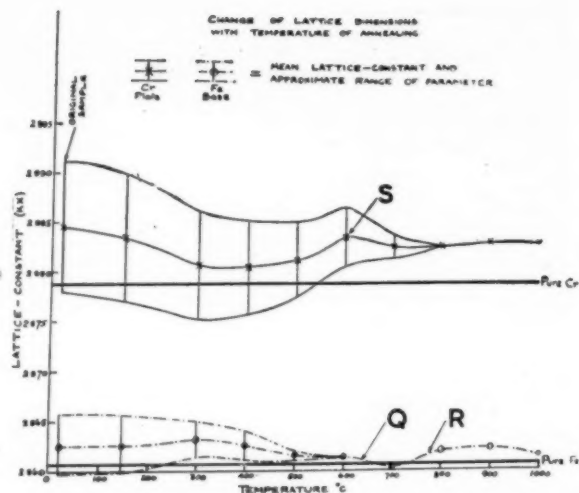


Fig. 5.—Hard chromium plating: low quality type.

outside so that the parameter decreases again somewhat. The maximum S at 700°C. and the consistent rise between 500° and 600° C. appears to correspond to a second stage in the release of hydrogen, a "second burst" as it were, of atoms held more firmly in the lattice than those evolved at the lower temperatures. Even at the highest temperatures, for instance at 1,000°C., and after any lattice distortion has disappeared, the chromium lattice dimensions are still larger than those of pure chromium. Unless therefore, it is assumed that a foreign element is present in solution in the chromium, for instance nitrogen (for which there is no evidence), this would prove that some hydrogen still remains in solution even at temperatures as high as 1,000°C.; but in contrast to the low temperature hydrogen causing lattice distortion, this residual hydrogen probably forms a stable interstitial solid solution in which hydrogen occupies regular positions of lowest free energy in the chromium lattice in the manner of a hydride; to "de-gas" this last residue, still higher temperatures would be required. The hydrogen atoms which had produced the highly-strained lattice at lower temperatures had not then occupied stable positions but had apparently been trapped in irregular places within the lattice, causing considerable fluctuations in spacing and lattice strains. It is, of course, this distorted state which is desirable in practice, as it is the one associated with hardness. Three distinct classes of occluded hydrogen may therefore be distinguished according to the degree of firmness of their binding in the lattice.

(a) That producing severe lattice distortions and largely expelled at low temperatures up to approximately 400°C.

(b) That held more firmly in the chromium lattice and expelled in a "second burst" at approximately 600°/700°C. (maximum S).

(c) That forming a genuine solid solution not straining the lattice but occupying stable lattice positions and causing permanent expansion of the chromium structure, which is probably not expelled until temperatures much higher than 1,000°C.

Considering Fig. 4 again, the lattice dimensions of the steel base have fallen nearly to those of pure ferrite by 500°C., whereafter they remain fairly constant. Slight

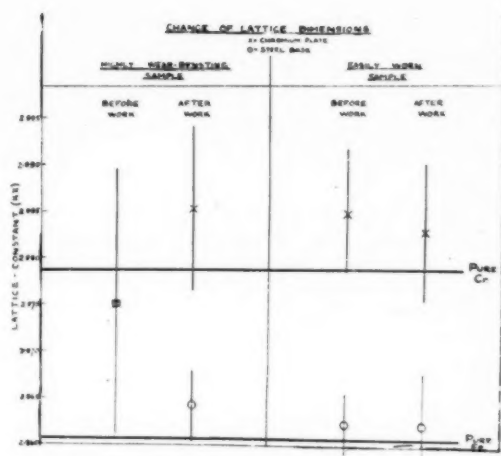


Fig. 6.—Effect of stroking action on hard chromium plate.

fluctuations observed (decrease at Q and rise at R) may be explained by the precipitation and re-solution of carbide in the steel, and the crossing of the eutectoid temperature.

Fig. 5 shows the lattice spacing curve for the chromium plate sample which had given poor properties. In contrast to the good sample, the two lattices are entirely separate throughout, but above approximately 400°C. the variation is very similar in both cases: in particular the maximum S repeats itself, indicating the second effusion of hydrogen.

The following subsidiary features may be noted from Fig. 2.

(1) If the good sample is annealed at 400°C. it assumes a structure which the poor one possessed originally.

(2) Not until approximately 500°C. have the good and the poor samples become similar in structure.

(3) Micro-strains in the chromium plate had in both cases been removed at approximately 700°C.

(4) Recrystallisation occurred in the steel base at approximately 700°C., whereas there are no signs of this for the chromium plate at the temperatures used. Preferred orientation in the chromium plate is evident in all cases from the full back-reflection photographs, which are not reproduced.

The practical outcome of this part of the investigation would be therefore that, to produce high quality hard chromium plating, such conditions have to be created in the electrolytic bath that a metastable lattice linkage between the steel base and the chromium deposit can be artificially produced, which, in tending to dissociate, causes very considerable lattice strains.

There is no reason to believe that the principle of plating metals on to specially chosen bases of lattice dimensions such that metastable lattice linkage is produced with consequent strains, will be restricted to chromium plating only, but will not similarly apply to the electro-plating of other metals (e.g., nickel, copper, zinc, etc.).

3. Effect of Cold Work

It has been mentioned that the chromium plating had to withstand a mechanical stroking action without wear. The highly wear-resistant sample was therefore

examined by X-rays before and after a severe wear test. The result was that the single line of the original sample reveals after test the beginning of resolution into the separate iron and chromium halos. The mean lattice parameters are shown in Table I and in Fig. 6, where the change in lattice dimensions and line width is given as affected by the stroking process. The lattice unity is therefore sensitive to external frictional force, which gradually break down the lattice linkage. It is in effect, strain relief produced by frictional working; but the distortion in the present case is still sufficiently great to maintain the hardness and wear-resisting properties in the "good" sample. The low-quality sample on the other hand, after being subjected to a similar test, shows no appreciable change in lattice dimensions, both phases having already been separate originally. In this case, the stroking action has merely worn down the thickness of the chromium rather than altered the internal structure.

It may be said that the reason why hard chrome plating is hard and so wear-resistant is that the energy of external friction (stroking) is, for a long time, dissipated in relieving the existing high lattice strains without actually removing material, whilst in the low-quality chromium plate no such stress relief is needed and the cold working energy is immediately spent on direct abrasion. No doubt much further stroking action on the good-quality sample would continue the stress relief and eventually might also lead to softening.

4. Thickness Measurements on Chromium Plate

It has been found possible to make use of the simultaneous appearance of X-ray diffraction lines produced by the chromium layer and by the underlying steel base for determining the thickness of the chromium from the absorption it exerts on the iron reflection. The method is non-destructive and a trial has given excellent agreement between the X-ray result and the thickness observed under the microscope after sectioning. The principle is, of course, also applicable to other electro-plated metals or metallic coatings in general using a suitable radiation. It is intended to deal with this subject in a separate publication.

5. General Remarks

It has been assumed throughout that it is hydrogen which is chiefly responsible for the variation of lattice-spacing and distortion observed, since the occlusion of hydrogen in the cathode metal in the electrolytic bath is a well-established fact. From the point of view of atomic sizes, the hydrogen atom is quite capable of entering both the body-centred cubic ferrite and chromium lattices interstitially, if not in a stable then in a metastable solid solution, expanding the lattice. The radius ratio of non-metal to metal atom, according to Hägg,¹⁷ is for metal hydrides of the order of 0.3 as against 0.4 to 0.6 for carbides and nitrides; although both carbon and nitrogen form, in true equilibrium, only very small solid solutions in ferrite, the formation of martensite and of an expanding nitrogen solution in it (e.g., in nitrided layers) proves that even these larger atoms are able to enter the lattice in metastable solution, so that this is all the more probable for hydrogen.

The hardness and wear-resistance have, in the present investigation, been explained mainly by the lattice-linkage effect. It is not doubted, however, that these

¹⁷ Hägg. *eg. Zeit. Phys. Chem., B*, 12 (1931), 33.

properties are also governed by further factors, in particular for thicker hard-chromium coatings, which commercially range up to 0.02 in. (as against the present thickness of 0.0001 in.). In these cases, the properties at the outer surface can no longer be appreciably influenced by the manner of bonding to the metal base. As Hume-Rothery and Wyllie have shown, the degree of preferred orientation possesses a definite relationship with hardness for thicker layers, and ultimately it might be expected that the inherent properties of the chromium layer prevail, independent of the base, but as influenced by its occluded hydrogen. It therefore would appear that two distinct effects are superimposed: (a) during the initial stages of deposition and for thin layers—the effect of the base metal and linkage with it, and (b) as deposition proceeds, and for thicker layers—the effect of crystal orientation which is primarily governed by electrolytic factors (defined lattice-directions following the lines of current flow). In (b) the effect of crystallite size may also enter. It is considered that both effects overlap but that with increasing thickness effect (a) will diminish (though not necessarily disappear entirely), and effect (b) prevail. The actual range of thickness values within which each effect dominates cannot be generally stated, since it will greatly depend on current density, temperature, bath constituents and the condition of the base metal lattice. The present samples are concluded to be in the region where the properties were governed by effect (a), although preferred orientation evidently also occurs, being probably more pronounced in the outer zones of the deposits.

It is of interest in this connection to consider the concepts of hardness and of wear resistance separately. Wear resistance (for instance during the present stroking action parallel to the surface) is more obviously related to the lattice linkage than hardness, in so far as poor adhesion of the plating to the base and poor cohesion within the plating itself will accelerate wear: and "adhesion" is the property most evidently connected with lattice linkage, with which it is almost synonymous. On the other hand, the manner in which hardness is influenced by lattice linkage and the presence of hydrogen is through the lattice strains and distortion produced and, using a simplified picture, the resistance to slip and to the propagation of dislocations offered by the "keyed" lattice planes. Wear resistance will in turn tend generally to be improved by increased hardness, so that this property is affected by lattice linkage in a two-fold manner, namely, through improved adhesion, and through increased hardness.

CONCLUSIONS

The conclusions drawn from this investigation may be summarised as follows.

(1) Hard chromium deposits of high and of low quality (wear resistance, hardness) differ very considerably in structure. In the good type large lattice strains exist such that the lattice of the steel base matrix (martensite or ferrite) is expanded, the chromium lattice contracted, the result being a metastable linkage of the two metals into one lattice at their interface. The agent facilitating this linkage appears to be hydrogen occluded in the steel base previous to any appreciable deposition of chromium, and expanding the structure so as to permit the subsequent chromium deposit to adapt

its unit cell dimensions to those of the base. This lattice linkage effect is unnatural to both the chromium and the steel base, so that, in their tendency to dissociate, considerable strains are produced. These strains are believed to be the essential reason for the hardness. In the poor quality chromium plate the Fe and Cr lattices were entirely separate to begin with and relatively unstrained.

(2) No interdiffusion of chromium and iron occurs, as proved by annealing at increasing temperatures. Annealing gradually expels the hydrogen, relieving strains and removing the "lattice linkage" effect; but not until approximately 500°C. has the structure of the good sample become similar to that of the poor one.

(3) In the good quality plate a reversal of the sign of strain and a maximum of mean lattice spacing at 150°C. shows the transit of hydrogen previously occluded in the steel through the chromium layer. A second maximum at approximately 600°/700°C. indicates a further release of hydrogen kept in solution at lower temperatures.

(4) It required a 400°C. anneal to relieve the stresses in the good plate to a state possessed by the poor one initially.

(5) Even in the strain-free state attained by the chromium plate after annealing at high temperatures (800/1,000°C.), lattice dimensions are obtained greater than those of pure chromium. This is explained as probably due to a small stable solid solution of hydrogen in the chromium lattice which requires a temperature well above 1,000°C. to facilitate its escape.

(6) Three classes of occluded hydrogen may thus be distinguished corresponding to different degrees of firmness of binding in the lattice, and different temperatures of release. Great hardness is associated only with the first, strain-producing class.

(7) In the steel base, the precipitation and re-solution of cementite is reflected by minor changes in spacing. Recrystallisation (crystal growth to approximately 10^{-2} cm.) occurs in the ferrite base above 700°C., but not in the chromium plate.

Preferred orientation in the chromium layers is pronounced in all cases, whereas the steel base shows a completely random orientation.

(8) External frictional shear stress (stroking action) in service partly relieved the lattice distortion and lattice linkage in the good sample. In the poor one, in contrast, the cold work hardly affected the structure, having been comparatively free from strain to start with: its only effect was to wear down the (already soft) chromium layer.

In other words, the energy of frictional work has been dissipated as strain relief in the high quality deposit, but as actual abrasion in that of low quality.

(9) It is possible to determine by X-ray diffraction the thickness of chromium plate in a non-destructive manner from the reduction in intensity of the steel base line by the overlying chromium.

Acknowledgment

The writer wishes to express his sincere thanks to Mr. D. A. Oliver, Director of Research of the B.S.A. Group of Companies, for his advice and encouragement, and to Messrs. Monochrome Ltd., Redditch, for presenting the problem.

Bronze Founding—

A Review of Some Recent Developments

By Frank Hudson, F.I.M.

The production of sound castings is of great importance to the engineer and much has been done in recent years to effect improvement in their quality. In a recent paper, read before Belgian foundrymen at Brussels, Mr. Hudson discussed some recent developments in bronze founding in which he directed particular attention to alloying and melting, and to pouring, feeding and moulding methods. By courtesy of the author we present his paper for British readers.

MUCH work has been carried out in the past few years to effect improvements in the production of bronze castings, but it is not possible to deal with this subject as comprehensively as one might wish. Instead attention is directed more particularly to some of the main developments, which have taken place in Great Britain and America, concerned with the production of quality castings for engineering purposes. Broadly speaking, these can be divided into two main groups:—Developments connected with alloying and melting methods, and those connected with pouring, feeding and moulding methods.

Developments connected with Alloying and Melting Methods

Effects of Dissolved Gas on Casting Quality.—As a result of the excellent work done by the British Non-ferrous Metals Research Association,¹ sufficient information is now available to enable the practical foundryman to understand and control the effects of dissolved gas in copper-base alloys.

Hydrogen is readily soluble in the majority of non-ferrous metals and is, therefore, the most usual cause of gas-porosity. It should be emphasised that the rate of solution of nascent hydrogen—i.e., that derived from reaction between the metal and water vapour in the atmosphere or sand mould—is much more rapid than that of dry molecular hydrogen.

Until quite recently it was thought that all castings should be free from dissolved gas, but it is now appreciated that in some instances the presence of a small amount of gas is actually beneficial. For example, in the production of aluminium bronze die-castings the presence of a small percentage of hydrogen reduces shrinkage and contraction troubles likely to cause "hot-tears." Due to rapid solidification of the metal the hydrogen is, of course, retained in solution. In the case of gunmetal and bronze sand castings, particularly those which are imperfectly fed, it has been found that in some instances the presence of a certain amount of gas² serves to disperse shrinkage-porosity more uniformly through the casting, with the result that pressure-tightness and mechanical strength are considerably improved. The effect of gas on the distribution of porosity varies considerably with different bronzes as follows:—

1. In copper-tin-zinc gunmetals, tin bronzes and phosphor bronzes containing up to 0.3% phosphorus

the presence of a small amount of hydrogen slightly improves the distribution of shrinkage-porosity, with some resultant improvement in the properties and pressure-tightness of imperfectly fed castings.

2. Degassed phosphor bronzes containing over 0.3% phosphorus absorb a small amount of hydrogen from moisture in sand moulds and this gas-absorption is most effective in dispersing local concentrations of shrinkage-porosity.

3. Leaded gunmetals are the best alloys for intricate castings which are not easily fed. The presence of even small amounts of hydrogen is harmful and they should, therefore, always be used in the fully degassed condition.

TABLE I.
SOLUBILITY OF HYDROGEN IN SOME NON-FERROUS METALS
(760 mm. Hg pressure of H₂)

Metal	Solubility of H ₂ in c.c.s. (NTP)/100 gm. Metal at—			
	Solidus	Liquidus	100° C. above Liquidus	200° C. above Liquidus
Copper	2.0	5.3	10.0	14.0
Nickel	18.5	39.0	41.0	—
Aluminium ..	Practically Nil	0.2	0.6	1.4

(Courtesy of The British Non-ferrous Metals Research Association).

The solubility of hydrogen in non-ferrous metals varies considerably, as shown in Table I. Many practical foundrymen are hesitant about using metals, such as nickel, capable of absorbing large amounts of hydrogen, as they think such metals are an inherent source of gassy metal. This, of course, is incorrect, and when trouble is experienced from this source it is generally due to bad production methods. The effect of various additions to copper on the solubility of hydrogen has been investigated by Sieverts³ as shown in Fig. 1. Nickel increases the solubility, whereas it is reduced by aluminium and tin. The increased solubility for hydrogen imparted to copper alloys by the addition of nickel may account to some extent for the use of this metal by foundrymen to promote solidity in castings. In view of the above it might also be suggested that nickel additions to most gunmetal and bronze castings are likely to be beneficial in counteracting the effects of hydrogen absorption arising from reaction with mould moisture.

Brasses and other alloys containing large percentages of zinc (probably over 10%) are not liable to absorb and retain hydrogen in the molten state, due to the high vapour pressure of zinc, which acts as a gas-scavenger.

Copper-nickel-zinc alloys, however, are prone to carbon monoxide gas-unsoundness, due to the reaction

¹ Baker, W. A. "Shrinkage and Gas Effects in the Casting of Non-ferrous Metals and Alloys." B.N.F.M.R.A. Report R.R.A. 661, 1944.

² Baker, W. A., Child, F. C., Glaisher, W. H. "The Effect of Shrinkage and Gas Porosity on the Pressure Tightness and Mechanical Properties of Bronze Sand Castings." *Jnl. Inst. Metals*, 1944, LXX, 373-404; disc., 557-591.

³ Sieverts, A. "The Absorption of Gases by Metals." *Zeitsch. Metallkunde*, 1929, XXI 37-44 disc., 45-46.

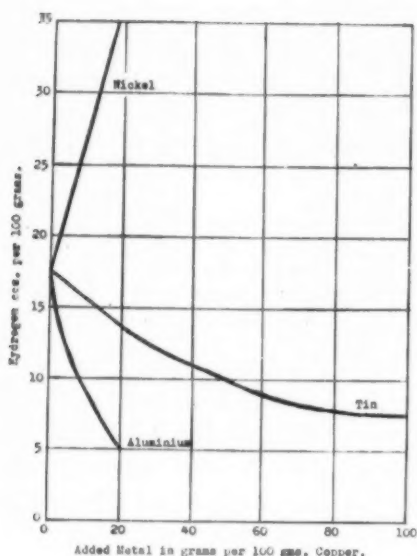


Fig. 1.—
Effect of
added met-
als on the
solubility of
hydrogen
in copper.

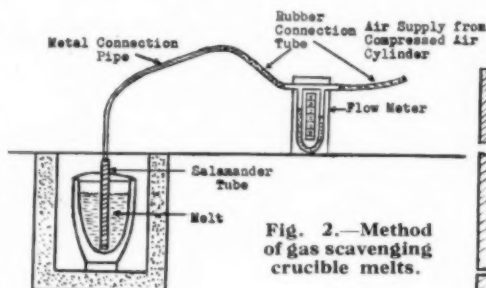


Fig. 2.—Method
of gas scavenging
crucible melts.



Fig. 3.—Section
through blow-
ing tube.

of carbon and active oxides in the melt, when they are melted under reducing conditions. Cupro-nickel and bronzes containing over 10% nickel are also susceptible to the above reaction, which can be prevented by the use of strongly oxidizing melting conditions.

From the practical point of view, particularly so far as the production of sand castings is concerned, it is wiser to avoid the presence of gas in the molten metal. In well designed castings which can be properly fed dissolved gas accentuates the effect of liquid shrinkage in promoting porosity and impairs mechanical properties. In badly designed castings of uneven section which cannot be properly fed the presence of a small amount of dissolved gas may prove beneficial with certain alloys. It is, however, not easy in practice to control the amount of gas required and the use of leaded gunmetals is undoubtedly to be preferred for the production of castings of varying section which have to withstand pressure. An extensive series of tests⁴ conducted in Great Britain some three years ago showed that an alloy containing 7% tin, 5% zinc, 5% lead, 3% nickel, balance copper, not only gave maximum pressure-tightness, with ease of handling in the foundry, but also produced stronger castings (when tested to destruction) at lower cost than any other available commercial tin-bronze or gunmetal.

Gas control during the melting operation.—During melting, copper alloys can absorb hydrogen from several sources such as :—

(a) The melting atmosphere, which may contain hydrogen and reducing gases. Water vapour in ordinary air, and in that used for combustion, is a common source of gas-absorption.

(b) Hydrated corrosion products, cutting-compounds, oil, etc., on the surface of the metal prior to melting.

(c) The presence of hydrogen in the metal used for the basis of the furnace charge—e.g., cathode copper, remelted ingots and scrap.

Until recently the most successful method for counter-acting hydrogen absorption during melting, was to melt as rapidly as possible in a slightly oxidising atmosphere

(0.2%–0.8% free oxygen), using a covering slag or flux which evolved oxygen on heating, and to follow by de-oxidation with phosphor-copper. Materials such as manganese dioxide (in the form of manganese ore), black copper oxide, nickel oxide, etc., are suitable for this purpose. Alternatively, a flux⁵ containing 1 part fused borax, 4 parts sand, 5 parts cupric oxide by weight can be recommended. It is claimed that this flux does not attack graphite crucibles. The amount of flux employed should be between 0.75–1.5% of the total

metal charge and sufficient to completely cover the surface of the molten metal.

The results obtained by this oxidation-reduction method are, however, affected by the type of material being melted. In the investigations conducted by the British Non-ferrous Metals Research Association,⁶ it has been shown that whilst plain copper-tin bronzes can be successfully degassed by an oxidation-reduction process, the presence of phosphorus and of zinc (to a lesser extent) prevents satisfactory results being obtained.

The presence of phosphorus lowers the solubility of oxygen in the melt and so hinders degassing by oxidation. Copper-tin alloys containing small amounts of phosphorus—e.g., up to 0.05% can be conveniently degassed by oxidation provided that the phosphorus is eliminated in the oxidation. It is, however, impracticable to remove large amounts of phosphorus by oxidation, and copper-tin-phosphorus alloys should be degassed by scavenging with dry nitrogen or air, or by the addition to the charge of substances which evolve inert gases during melting. Manganese ore, marble chips, etc., are fairly effective in this direction, providing they are charged at and remain on, the bottom of the crucible. When added to the surface of the melt, or mixed with fluxing agents, they do not act so well.

The presence of zinc has the same effect as that of phosphorus, but to a lesser degree. Alloys containing up to 1.0% zinc can be rapidly degassed by oxidation-reduction treatment. With higher zinc contents this treatment gives melts with a low gas content which is probably sufficiently low for most purposes, although they are not completely degassed. Complete degasification, however, can be effected by the gas-scavenging methods mentioned previously, although the evolution of zinc fume makes the process rather objectionable unless suitable precautions are taken.

Degasification by gas scavenging shows considerable promise as compared with the oxidation-reduction method utilising slags and fluxes. The former is a much cleaner operation, is less severe on crucibles and furnace-

⁴ Hudson, F. "The Use of Leaded Gunmetal for the Production of Castings to Withstand Pressure." *Jnl. Ind. Metals*, 1944, LXX, 407–422; disc., 557–591.

⁵ Pell-Walpole, W. T. "Development of a Flux Degassing Process for Chill-cast Tin Bronzes." *Jnl. Ind. Metals*, 1944, LXX, 127–147; disc., 557–591.

⁶ Baker, W. A., Child, F. C. "The Removal of Gases from Molten Bronzes." *Jnl. Ind. Metals*, 1944, LXX, 349–370; disc., 557–591.

linings and can be easily applied on a practical basis in the foundry. There is no need to dry the air or nitrogen if these are taken from cylinders at pressures exceeding 20 atmospheres. The gas is bubbled through the superheated metal, just before pouring, for a period of about 5 minutes, by means of a steel or refractory tube, as shown in Figs. 2 and 3. The rate of gas-flow (500-600 litres per hour) must be sufficient to cause a fairly violent disturbance of the metal. Some allowance should also be made for the cooling effect of the gas on the molten metal, which should be superheated to a higher temperature than normal. After the scavenging treatment the metal must, of course, be deoxidised in the usual manner. Suggested gases for treating various alloys are outlined in Table II. In view of the increasing use of electric furnaces in the brass foundry it may be interesting to note that it would not be a difficult matter to fit gas-scavenging methods as an integral part of such melting equipment. In the case of the rocking arc, and furnaces of similar type, the design could readily incorporate a special tuyère for introducing the scavenging gases to the melt with the minimum of trouble to the founder.

TABLE II.
SUGGESTED GASES FOR SCAVENGING VARIOUS ALLOYS

Alloy	Scavenging Gas
Phosphor Bronze. Aluminium Bronze.	Dry Nitrogen.
10-12% Tin-Bronze. High Nickel Tin-Bronze. 88/10/2 Gunmetal. 86/7/5/2 Gunmetal. 83/7/5/5 Gunmetal. 85/5/5/5 Gunmetal. Nickel Silver (under 10% zinc). Cupro Nickel.	Dry Air.
Yellow Brass. High-tensile Brass.	Degasification not usually required.

TABLE III.
MAXIMUM AMOUNTS OF PHOSPHORUS REQUIRED TO DE-OXIDISE DEGASSED TIN BRONZE

Degassing Medium	% Phosphorus Required
Manganese Ore at bottom of crucible	0.04
Flux cover { 1 part cupric oxide. 2 parts sand. 2 parts Borax.	0.06
Flux cover { 1 part cupric oxide. 1 part Sand. 1 part Borax.	0.08
Scavenging with dry air.	0.08

Deoxidation.—The amount of phosphorus required to deoxidise degassed gunmetal and ordinary tin-bronzes will vary according to the degree of oxidation treatment given to the metal, as indicated in Table III. These phosphorus percentages represent maximum additions to the molten metal: the residual phosphorus content in the final castings should be considerably less than the figures shown and preferably around 0.01-0.02%.

Melting furnaces.—During the last few years there have been no radical changes in the design of furnaces for non-ferrous metal melting. As mentioned previously, greater interest is being shown in the use of electric melting methods. Lift-coil induction furnaces are the latest to be added to the range of equipment produced in Great Britain by Birlec, Ltd. The lift-coil furnace is easily adapted to existing lay-out, takes up little space, and can be switched from one alloy to another simply by substituting another crucible. The advantage of greater



Fig. 4.—Lift-coil induction furnace (Birlec Ltd.).

flexibility overcomes its slightly lower efficiency and, more important still, no ladles are required. One particularly useful arrangement of the lift-coil furnace embodies two crucibles mounted on a bogie and track arranged with end stops, as shown in Fig. 4. After the first crucible of metal is melted the induction coil is lifted and the bogie is moved to position it automatically for melting the metal in the second crucible.

Due to the coal shortage in Great Britain, and the Government's endeavour to relieve the position by subsidising the use of oil, a considerable amount of old plant has been replaced by modern types of oil-fired furnaces similar to that shown in Fig. 5. Considerable attention has been given to the incorporation of clear-reading blast gauges and fixed burners, to maintain maximum fuel-efficiency.

In the case of gas-fired furnaces automatic burners are being developed, in which the air- and gas-supplies are operated by a single control.

Developments connected with Pouring, Feeding and Moulding Methods

Pouring methods.—During the past few years slow-pouring methods have been adopted in Great Britain with marked success, for the production of chill-cast solid and cored bronze and gunmetal sticks and billets. Whilst slow-pouring methods are by no means new, their application in the non-ferrous foundry has received a marked incentive following the work done by Pell-Walpole⁷ in collaboration with the Tin Research Institute. When used in conjunction with metal suitably degassed by oxidation-reduction or gas-scavenging, and properly prepared mould and cores, slow pouring effects a very marked improvement in the quality of all bronze and gunmetal sticks and billets varying in size from 1-12 in. in diameter.

From the results of the above investigation it has been found that the use of certain types of aluminium paint for dressing chill moulds prevents "blowing" and gives improved surface-finish on the bronze stick. It should be emphasised, however, that only those

⁷ Pell-Walpole, W. T. "Improvements in Hollow Sticks and Billets by Casting on to Metal Cores." *Foundry Trade Jnl.*, 1947, LXXXI, 285-293.

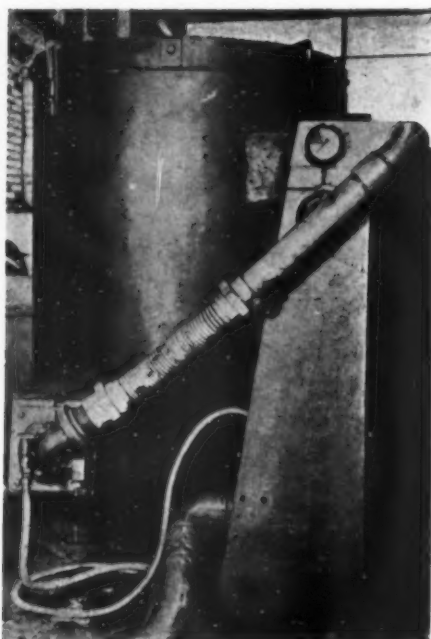


Fig. 5.—
Modern
design of
oil-fired
crucible
furnace.

(Morgan
Crucible
Co., Ltd.).

aluminium paints with a strong resinous or oily base should be used.

For the production of hollow chill-cast sticks and billets it is recommended that an asbestos-wrapped core should be employed for cores up to $2\frac{1}{2}$ in. in diameter, and a split chill-core for larger sizes.

For cores up to $2\frac{1}{2}$ in. diameter and up to 3 ft. long, wrap with asbestos paper (0.015 in. thick), allowing one complete wrapping per 1 in. thickness of the steel- or iron-core tube, which should have a smooth surface and preferably be tapered $\frac{1}{16}$ in. on diameter per ft. of length. For parallel cores double this thickness of asbestos paper is required. The paper must be sealed on to the core tube with a suspension of 5% aluminium powder in a 2% solution of dextrin or core-gum in water, which also acts as the core-coat. The coated core should be baked for not less than 15 minutes at $300^{\circ}\text{C}.$, before use. After the casting has solidified, and cooled to about $300^{\circ}\text{C}.$, it should be quenched in water and allowed to stand for a few minutes when the core should knock-out readily.

Cores having a diameter greater than $2\frac{1}{2}$ in. should be split vertically into four uniform sections and a cut of 0.015 in. per in. of core-diameter should be taken from each radial face. The four sections are then heated to about $100^{\circ}\text{C}.$, dressed with resinous aluminium paint, and set up in the mould with asbestos paper inserts (previously baked at $300^{\circ}\text{C}.$) as shown in Fig. 6. When the casting has cooled to approximately $300^{\circ}\text{C}.$, one-quarter of the core may be knocked-out, so releasing the others.

In both the above cases the casting should be slowly top-poured, preferably through a preheated moisture-free refractory basin with jet runners. The pouring rate is obtained from the formula $R = KD$, where R is the rate in pounds per minute, K a constant depending on phosphorus content, D the sum of the internal and external diameter of the casting. K should be taken as 6 when phosphorus content is less than 0.25%, and 5

for 0.5–1.0% phosphorus. The number of jet runners employed should be as follows:—

Two jet runners for castings up to 2 in. dia.

Four jet runners for castings up to 4 in. dia.

Six jet runners for castings up to 8 in. dia.

Twelve jet runners for castings above 8 in. dia.

Following the successful results obtained by the use of slow-pouring methods for chill-cast sticks and billets, several British foundries have applied a similar technique to the production of large sand castings, with promising results. In general, however, the best results on copper-base alloy castings have been obtained by adopting the gating methods exemplified in Figs. 7 and 8.

When pouring aluminium bronze or high-tensile brass, an endeavour is made to avoid dross-formation by utilising gating methods which give streamline flow. Turbulence is avoided as far as possible by bottom-pouring, using one or more tapered ingates, with the large end against the casting and the total area of the small ends slightly less than the area of the downgate. These principles are clearly outlined in the photograph of the small aluminium bronze propeller casting shown in Fig. 7.

In the founding of gunmetal and bronze castings, particularly those required to withstand pressure, the modern tendency is to utilise choke gates directly connected to the risers or feeding heads, as illustrated in Fig. 8, rather than the older practice of direct riser pouring.

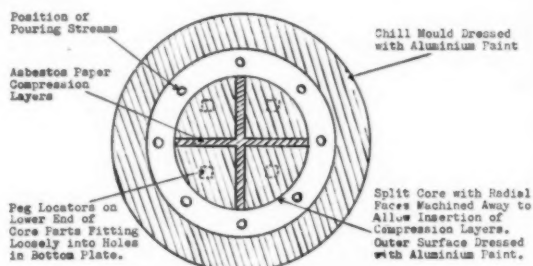


Fig. 6.—Mould assembly for slow-pouring cored billet with split chill core (Pell-Walpole).

Feeding methods.—In 1942, the development of atmospheric feeding methods (Fig. 9) in the United States by Taylor and Rominski⁸ created considerable interest in foundry circles and received wide publicity in the technical press. This development may be superseded by the gas-pressure feeding methods recently suggested in Great Britain by Jazwinski and Finch.⁹ In brief, high-pressure feeding is effected by enclosing within the feeding head a small capsule containing materials which, after a short delay, liberate both heat and an inert gas under pressure. A diagrammatic drawing of the arrangement is given in Fig. 10. The purpose of the delay, controlled by the time required to melt the container of the capsule, is to ensure solidification of the outside surfaces of the feeding head and downgate so that the full pressure of the liberated gas forces liquid metal into the casting. It is claimed that by the use of this method sound steel castings are obtained, with a yield varying from 75–95%, against 60% using ordinary

⁸ Taylor, H. F., Rominski, E. A. "Atmospheric Pressure and the Steel Casting: A New Technique in Gating and Riserless." *Trans. Amer. Foundry Assoc.*, 1942, L, 215–251; disc., 252–259.
⁹ Jazwinski, S. T., Finch, S. L. "High-pressure Feeding of Static Moulds." *Foundry Trade J.*, 1945, LXXVII, 268–274; 293–302.

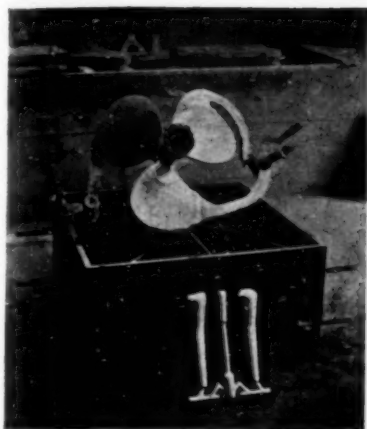


Fig. 7.—Satisfactory method for running aluminium-bronze castings.

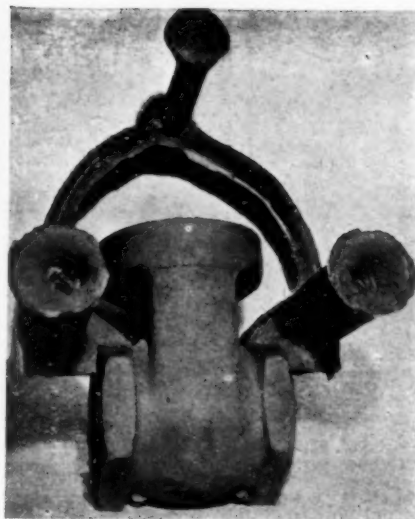


Fig. 8.—Satisfactory method for running gun-metal and tin-bronze castings.

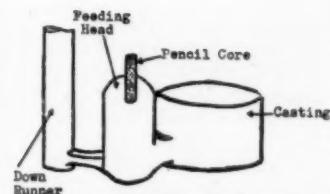


Fig. 9.—Atmospheric feeding methods (Taylor and Rominski).

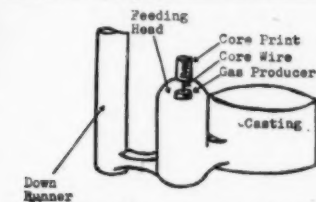


Fig. 10.—Gas-pressure feeding methods (Jazwinski and Finch)

gravity feeding-heads. Experiments now being conducted with gas-pressure-heads on copper-base alloy castings are giving encouraging results.

Necked or "knock-off" risers are being increasingly employed, both in Great Britain and the United States, to facilitate and reduce the cost of their removal from the casting. In the production of iron and steel a thin core is usually inserted between the feeder and the casting to form the "neck." So far as brass and bronze castings are concerned, the latest information ^{10, 11} indicates that the use of graphitic carbon discs, in conjunction with heat-insulated riser sleeves, is to be preferred. The carbon discs can be made from graphite electrodes and the size of disc selected for any given riser is always 2 in. larger than the diameter of the riser, thus allowing a 1 in. circumferential shoulder for a print. On the top surface of this print is placed a gypsum or other heat-insulating sleeve. (See Fig. 11). The central hole in the carbon disc should be 20–25% of the diameter of the riser. To ensure breakage of the riser slightly above the casting surface, both the top and bottom edges of this central hole are beveled with a file. (Occasionally several $\frac{1}{8}$ in. diameter holes are drilled midway between the centre and outside edges of the carbon to aid venting of the mould). The thickness of carbon disc required varies according to the diameter of feeding head employed, as follows:—

Thickness of carbon disc.	Diameter of Feeding head or riser
$\frac{1}{8}$ in.	up to 6 in.
$\frac{3}{16}$ in.	6–10 in.
$\frac{1}{4}$ in.	over 10 in.

Castings are generally run from the bottom until the metal comes through the riser neck, after which pouring is completed down the riser.

The gypsum riser sleeves are made from equal parts (by weight) of gypsum, to which has been added 20% portland cement, and water. This slurry is poured into metal moulds to form the sleeves, following which they are air-dried for 2 hours and then baked at 260° C. for 10 hours.

Necked risers may effect as much as 45% reduction in fettling costs when removing 3-in. diameter risers and up to 80% with 9-in. risers. Furthermore, the use of gypsum sleeves enables the risers to be made 30% smaller than when made in the ordinary way without sacrifice of feeding power. In many instances feeding may actually be improved.

A material recently developed in the United States by the Pittsburg Metals Purifying Co., called Thermotomic,¹² shows interesting possibilities as an alternative to the graphite discs used in necked risers. This material is supplied in a form much like sand and only requires mixing with 4–6% water before using. After ramming into the required shape it is thoroughly dried at 180–200° C. On contact with molten metal it glows with a strong but controllable exothermic reaction. In a confined area, such as a feeder head, temperatures in the range of 400° C., will start the reaction. It is claimed that Thermotomic will impart no impurities to the metal and that it has no detrimental effect on foundry sands. It is possible that this material might also act as a substitute for the "gas-producing" capsule utilised by Jazwinski and Finch in their gas-pressure-feeding methods.

Moulding methods.—Research of a fundamental nature conducted by both the British Non-ferrous Metals Research Association² and by Pell-Walpole¹³ has shown that degassed metal may be spoiled by contact with moisture, whether from pouring basins or from sand in the moulds, etc. This effect is particularly noticeable in phosphor bronzes, and the amount of gas absorbed, and the resultant degree of gas-unsoundness, increases with the phosphorus content of the melt. For example, alloys containing 10% tin and up to 0.3% phosphorus absorb very little gas when poured at temperatures up to 1,130° C. With larger phosphorus contents and higher pouring temperatures considerable gas-absorption occurs. Drying the sand mould at 200° C. does not prevent gas-absorption, but drying at temperatures between 800–900° C.—e.g., high enough to dehydrate

¹⁰ Brinson, S. W., Duma, J. A. "Knock-off Risers for Non-ferrous Castings." *Amer. Foundryman*, 1946, X, Oct., 55–62.

¹¹ Taylor, H. F., Wick, W. C. "Use of Heat-insulating Pads and Riser Sleeves for Producing Sound Bronze Castings." *Foundry*, 1945, LXXIII, Oct., 88–92, 158, 160, 164, 166, 168, 171, 175; Nov., 106–111, 260, 262.

¹² Lloyd, T. E. "Thermotomic—a New Feeding Technique for Castings." *Iron Age*, 1946, CLVII, April 25, 62–64.

¹³ Pell-Walpole, W. E. "The Gassing of Bronzes by Reaction with Moulding and Core Sands." *Foundry Trade Jnl.*, 1946, LXXVIII, 87–89, 147–150, 163–167, 209–210, 235–238, 240.

the clay bond, eliminates the effect. A great deal of work still needs to be done in the study of "metal-mould" reactions before a complete answer to this problem is obtained, but in the meantime it is interesting to note that properly dried moulds made from silica or sea sand bonded with linseed oil and dextrine give minimum gassing. In the production of phosphor bronze sand castings it is important to keep the phosphorus content as low as possible, and certainly below 0.3%, or alternatively to employ a mould which will not evolve water vapour when heated.

This review would not be complete without some mention of the recent work done by British non-ferrous founders and users of castings, in co-operation with the British Standards Institution, in evolving a Code of Procedure in the Inspection of Copper-base Alloy Sand Castings.¹⁴ This code bases the assessment of quality on the casting itself, according to the duty it has to perform, and fixes the function of separately cast test bars, of standard form, only as an index of the quality of the material employed for casting production. It is emphasised that the true function of a test bar is to provide an indication of the quality of the metal from which it is cast. It must, therefore, be sensitive to the effects of dissolved gas, which is not always evident on many types of test-bars at present in use. Furthermore, from the economic point of view, the form of test-bar adopted as a standard should entail minimum wastage of metal and machining time, and yet provide adequate means of easily obtaining a sound and fully-fed bar.

¹⁴ Brit. Standards Instn. B.S.S. 1367, 1947.

The Steel Company of Wales Ltd.

THE scheme for the further modernisation of the tinplate and sheet industry in South Wales is being carried into practical effect by the above, recently incorporated, Public Company. In connection with this scheme Guest Keen Baldwins Iron and Steel Co. and John Lysaght Ltd. have entered into an agreement to transfer certain of their undertakings to the new Company.

Guest Keen Baldwins Iron and Steel Co. has transferred the undertakings which it carried on at Port Talbot and Margam Works and at Cornelly Quarry, and John Lysaght Ltd. has transferred its Orb Works at Newport. The transfer was carried out as from the close of business on September 27th, 1947, and these works, with their plant, machinery, stock-in-trade, and goodwill, are now vested in The Steel Company of Wales. The latter Company has thus taken over the obligations and benefits of all contracts and engagements in respect of the transferred works. The East Moors Works, Cardiff, and those at Dowlais, will continue to be operated by Guest Keen Baldwin Iron and Steel Co. Ltd., while the businesses of John Lysaght, Ltd., at

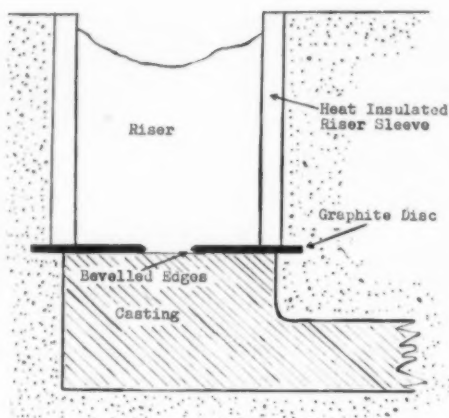


Fig. 11.—Use of graphite discs and gypsum sleeves for necked risers.



Fig. 12.—Standard form of test bar.

With these facts in mind it is recommended that the design shown in Fig. 12 should be tentatively adopted as a standard form of test-bar for copper-base alloy castings and that it should be used wherever possible. Preliminary tests¹⁵ have indicated that the properties obtained from this type of test-bar are likely to satisfy the demands of most British Standard Specifications for cast copper-base alloys, providing they are properly treated in the foundry.

Inspection methods of this kind are quite new to makers of copper-base alloy castings, although familiar enough to light alloy founders producing aircraft parts. They provide the incentive for improving the quality of castings, and lead to greater co-operation with the designer and user. They are, therefore, likely to play no small part in future developments in the brass foundry.

¹⁵ Hudson, F. "Standard Test Bars for the Non-ferrous Foundry." *Foundry Trade Jnl.*, 1946, LXXIX, 185-191; disc., 451-454; *ibid.*, LXXX, 31-37.

Bristol, Scunthorpe and London will be carried on as heretofore, and the London Office at 66, Cannon Street, will continue to deal with the products of the Newport Works.

The principal products manufactured by Guest Keen Baldwins Iron and Steel Co., orders for which will now be executed by The Steel Company of Wales and which should be sent to Port Talbot, include limestone; basic pig iron; angles, channels and joists; steel plates; rails over 40 lbs. per yard; fishplates for rails over 40 lbs. per yard; steel sleepers for heavy rails; and 3 in. x 2 in. and 4 in. x 2 in. steel slabs. The products which will continue to be manufactured by Guest Keen Baldwins Iron and Steel Co., and for which orders should be sent to East Moors Works, Cardiff, include basic and hematite pig iron; billets, bloom and slabs; sheet bars; arches, props, and roofing bars; light rails under 40 lbs. per yard; and sleepers for colliery rails.

Guest Keen Baldwins Iron and Steel Co. will continue to roll sections at the Cardiff works but have requested The Steel Company of Wales to deal with orders for all sections until further notice.

Some Observations on the Occurrence of the "Grain Boundary Gamma" Phase in a 2% Beryllium 0.25% Cobalt Copper Alloy

By P. J. E. Forsyth

Specimens of a 2% beryllium 0.25% cobalt copper alloy in the annealed and half-hard condition have been subjected to various solution heat-treatment and tempering treatments. Quenching tests were then made to determine the effect of the quenching rate on the amount of grain boundary precipitate. The microscopic examination of the specimens is discussed and some conclusions given on the grain boundary gamma phase as a result of this work.

THE desirable properties of the beryllium-copper alloys are obtained in commercial practice by two heat-treatments. The first the solution heat-treatment at about 800° C. followed by a water quench and the second a tempering or precipitation hardening treatment at about 310° C.

The microstructure of the alloys in the heat-treated condition invariably contains a certain amount of a precipitated phase at the grain boundaries. The detrimental effects of this phase on the properties of the beryllium-copper alloys make it desirable to suppress its formation as completely as possible. It assumes bulky proportions under certain heat-treatment conditions, resulting in distortion of the material. Another important effect, which has been described by Williams,¹ is the lowering of what he terms the "available" beryllium content of the alloy by allowing the formation of this phase. The "available" beryllium content of the alloy is that amount which is free to cause hardening by its precipitation from the supersaturated alpha solid solution during the tempering or precipitation hardening heat-treatment. If part of the total beryllium is locked up in the form of "grain boundary gamma" or other phases, the alloy's response to the hardening heat-treatment will be lowered.

Grain-boundary precipitation is generally described as "discontinuous" precipitation as opposed to the continuous type which takes place within the grains themselves and is contributory to the general hardness of the alloy. The "discontinuous" type is met with in

many precipitation-hardening alloys, including light alloys, where it is usually associated with susceptibility to intercrystalline corrosion. Whereas in the light alloys the precipitate may be very fine and may only reveal its presence by etching pits; in the beryllium-copper alloys the grain-boundary precipitate takes a more massive form as will be seen from some of the accompanying photographs. The composition of this phase is not fully understood, but it is believed to be of a complex nature and microscopical observations show the phase to have a granular rather than a homogeneous structure.

A number of specimens of a 2% beryllium 0.25% cobalt copper alloy in the annealed and half-hard condition were subjected to the various solution heat-treatment and tempering treatments shown in Table I. Quenching tests were subsequently made to determine the effect of the quenching rate on the amount of grain-boundary precipitate.

All specimens were polished electrolytically, superior results being thereby obtained than were possible by the usual mechanical methods. An orthophosphoric acid bath (s.g. 1.38)² was used with a pure copper cathode and an external voltage of approximately 5 volts.

The strain-free surface obtained by electrolytic polishing is considered essential for the observation of minute detail at high magnifications, besides rapidly providing a scratch-free surface. Where possible the structure was examined in the "as-polished" condition, the slight etching effect produced by the bath under certain operating conditions revealing the microstructure.

1 Available beryllium in copper. H. G. Williams, *Metal Progress*, July, 1944.

2 Lowery, Wilkerson & Smare. *Phil. Mag.*, Vol. 22, p. 769, 1936.

TABLE I.—HARDNESS TESTS

Solution heat-treat at: and water quench	780° C.	800° C.	820° C.	840° C.	860° C.	880° C.
	d.p.h.	d.p.h.	d.p.h.	d.p.h.	d.p.h.	d.p.h.
As received (annealed)	104,104	102,104	100,101	9,999	9,898	99,100
As received + 1 hour at 315° C.	320,320	318,331	341,336	348,343	341,343	346,353
As received (half hard)	106,106	104,104	101,100	102,101	100,100	10,499
As received (half hard) + 1 hour at 315° C.	328,325	348,349	346,337	337,339	344,349	346,351

Annealed Material			Half-hard Material	
Tempering Temperature	1 hour	2 hours	1 hour	2 hours
	d.p.h.	d.p.h.	d.p.h.	d.p.h.
280	181,186	315,305	358,368	400,406
300	265,236	326,329	400,404	411,409
320	312,317	325,326	398,400	402,400
340	321,326	295,294	406,393	396,389
360	270,285	263,268	381,379	375,377

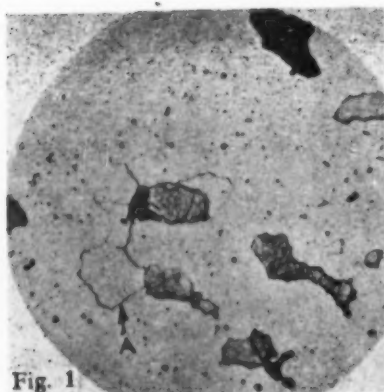


Fig. 1

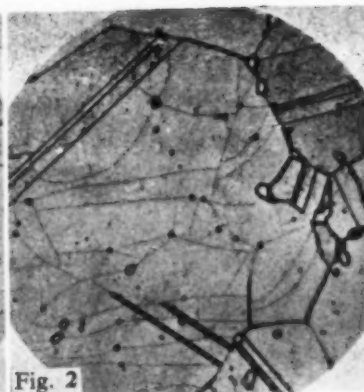


Fig. 2

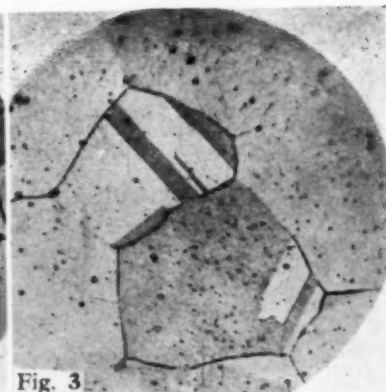


Fig. 3

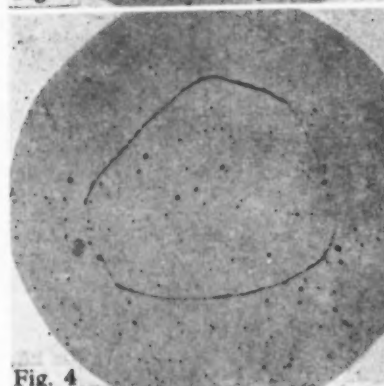


Fig. 4

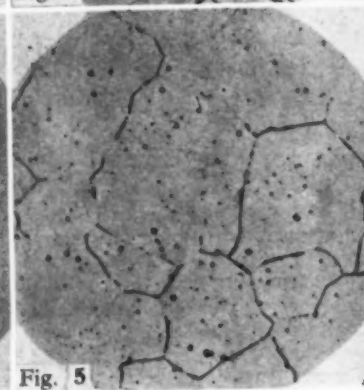


Fig. 5

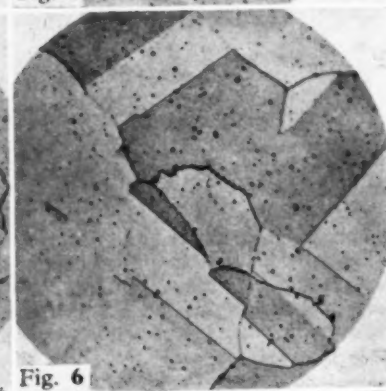


Fig. 6

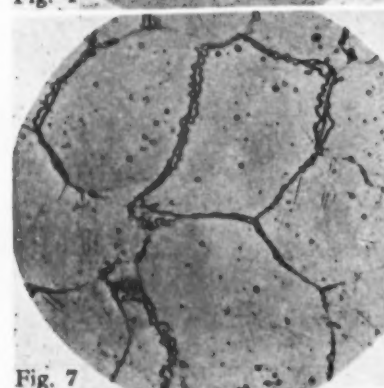


Fig. 7



Fig. 8

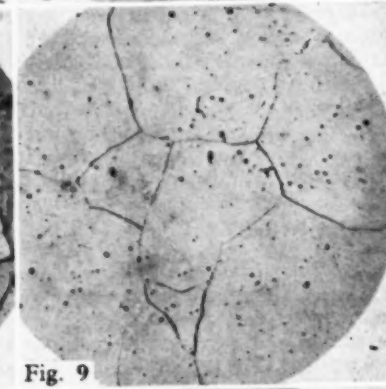


Fig. 9

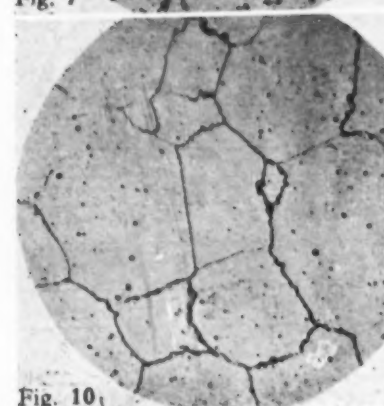


Fig. 10

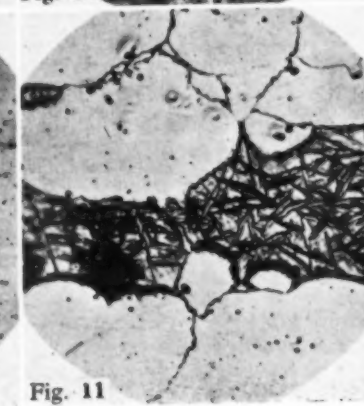


Fig. 11

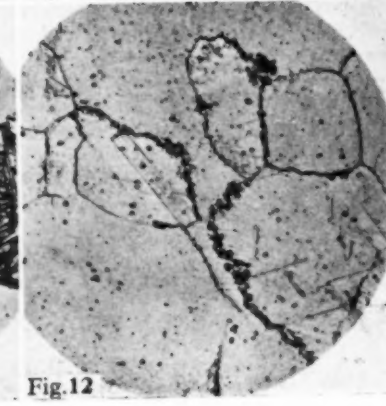


Fig. 12

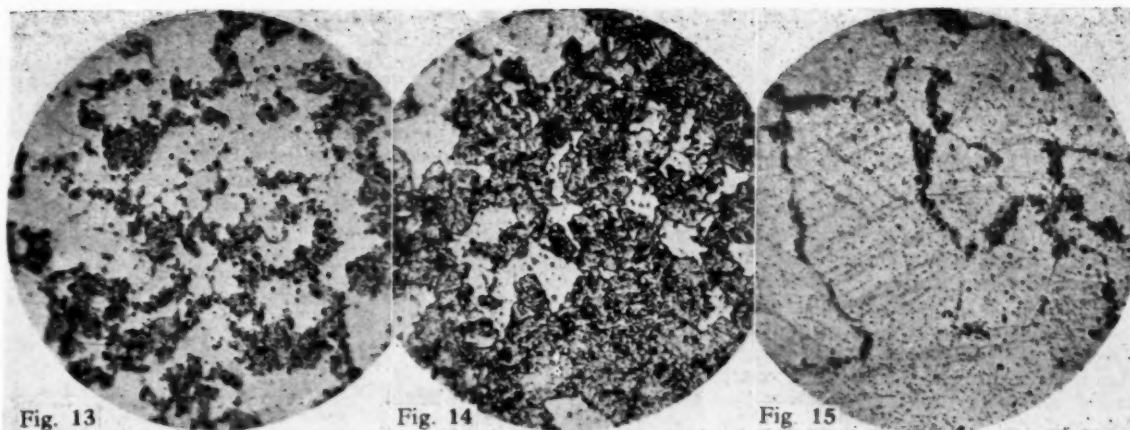


Fig. 1 $\times 1,000$	.....	Solution heat-treated and quenched
Fig. 2 $\times 250$	.....	Solution heat-treated and quenched
Fig. 3 $\times 1,000$	.....	Solution heat-treated and quenched.
Fig. 4 $\times 1,000$	.....	Solution heat-treated and quenched.
Fig. 5 $\times 1,000$	.....	Solution heat-treated and quenched.
Fig. 6 $\times 1,000$	.....	Solution heat-treated and quenched.
Fig. 7 $\times 1,000$	.....	Solution heat-treated 840°C . and quench + 315°C . for 1 hr.
Fig. 8 $\times 1,000$	.....	Solution heat-treated 800°C . and quench + 315°C . for 1 hr.
Fig. 9 $\times 1,000$	.....	Solution heat-treated 840°C . and quench rapidly
Fig. 10 $\times 1,000$	.....	Solution heat-treated 840°C . and quench slowly
Fig. 11 $\times 1,000$	.....	Solution heat-treated 840°C . and quench slowly
Fig. 12 $\times 1,000$	.....	Solution heat-treated 820°C . and quench + 315°C . for 1 hr.
Fig. 13 $\times 1,000$	.....	Solution heat-treated 800°C . and quench + 340°C . for 1 hr.
Fig. 14 $\times 1,000$	.....	Solution heat-treated 800°C . and quench + 360°C . for 1 hr.
Fig. 15 $\times 1,000$	.....	Solution heat-treated 800°C . and quench + 360°C . for 2 hrs.

TABLE II

.....	Electrolytic polish + electrolytic etch
.....	Mechanically polished. Copper-ammonium sulphate etch
.....	Electrolytic polish | Copper-ammonium sulphate followed by
.....	Electrolytic polish | $\text{FeCl}_3 + \text{HCl} + \text{alcohol}$ etch
.....	Electrolytic polish. Copper-ammonium sulphate.
.....	Electrolytic polish. Copper ammonium-sulphate.
.....	Electrolytic polish + electrolytic etch.
.....	Electrolytic polish + electrolytic etch.
.....	Electrolytic polish. Copper-ammonium sulphate
.....	Electrolytic polish
.....	Electrolytic polish
.....	Electrolytic polish
.....	Electrolytic polish
.....	Electrolytic polish

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The grain-boundary precipitate was usually more clearly revealed by subsequent light etching. A number of etching reagents were experimented with to show up specific details in the microstructure of this alloy. The best results were obtained with copper ammonium sulphate which gave a very clear grain-boundary etch to the solution heat-treated material, attacking the fine grain-boundary precipitate without causing a "step" between the grains due to preferential grain attack. Masing and Dahl³ found copper ammonium sulphate a good etching reagent for following the stages of precipitation in the copper-beryllium alloys.

Longer etching times with this etching reagent reveal twin markings and preferentially colours the different grains of solution heat-treated material. The matrix of specimens in the fully hardened condition was quickly blackened by this reagent leaving the β phase un-attacked. For etching the fully hardened specimens $\text{FeCl}_3 + \text{HCl}$ and alcohol was found to be the most satisfactory etching reagent, giving more contrast between the matrix and the "grain boundary gamma" than the copper ammonium sulphate.

The electrolytic method of etching suggested by Jacquet⁴ for homogeneous copper alloys has been successfully applied to beryllium copper. The specimen is electrolytically polished with the orthophosphoric acid previously described and after polishing the electrodes of the bath are short circuited. A polarisation current then flows, causing anodic oxidation of the grain boundaries of the specimen. The time required for a light grain boundary etch was found to be about 10 seconds, but will no doubt vary with the conditions of the bath.

Figs. 1 and 2 show the material in the solution heat-

³ Masing & Dahl. "Beryllium," Rimbach & Michel.
⁴ A very sensitive method of micrographic attack for copper. Pierre Jacquet (*Métallurgie, Corrosion-Usure*, 1944, 19, 229, p. 30, 94).

treated and quenched condition. Arrow A in Fig. 1 indicates the areas of β phase which were evident in the microstructure due to beryllium segregation. Fig. 2 shows the phenomenon known as "veining" which is sometimes observed in the alloys. Figs. 3, 4, 5 and 6 show material which has been solution heat-treated at 840°C . and water quenched to room temperature. The specimens have been etched in copper ammonium sulphate to reveal fine grain boundary particles. The grain orientations shown in Figs. 3 and 4 were revealed by an additional light grain etch with $\text{FeCl}_3 + \text{HCl} + \text{alcohol}$. The existence of the grain-boundary particles is discussed at greater length in the concluding paragraphs of this paper. The structure obtained after precipitation hardening the material is shown in Figs. 7 and 8. The different appearance of the constituents in the two photomicrographs shows the effects of different polishing bath conditions; both specimens are of the same material and in the same heat-treated condition. The effect of quenching speed on the amount of grain-boundary constituent which appears in the microstructure is shown in Figs. 9, 10 and 11. Fig. 9 shows the structure near the exposed end of a quench-test specimen where the rate of cooling was relatively fast, while Figs. 10 and 11 were taken near the centre of the same specimen. Fig. 11 also shows the start of the breakdown of the β phase into $\alpha + \gamma$.

Figs. 12, 13 and 14 show the effect of increasing temperature during the tempering or hardening heat-treatment on the amount of "grain-boundary gamma" precipitated. Fig. 15, which has been cold worked before the precipitation heat-treatment can be compared with Fig. 14 which has received no cold working and shows a much greater amount of the grain boundary constituent although only tempered half as long as the other.

Discussion of Microscopic Examination

It has been shown that the grain boundaries of a metal favour precipitation due to their higher free energy content. This will vary with the relative orientation of the two grains to the interface. The physical conditions favourable to grain-boundary precipitation from the alpha solid solution are therefore variable and will change with changes in direction of the grain boundary. Reorientation in certain boundary zones brought about by twinning will cause abrupt changes in the physical condition of the grain boundary and favoured positions of precipitation should appear.⁵ This is found to be the case and is clearly illustrated in the tempered specimens particularly Fig. 8 where the precipitate is indicated by Arrow B. This effect is also very noticeable in the solution heat-treated and quenched microstructures, Figs. 5 and 6, and it is, therefore, apparent that the particles are precipitated from the solid solution and are not impurities forced to the grain boundary. This is also confirmed by the fact that even after grain growth during the heat-treatment the particles still appear in the grain boundaries.

It appears that the particles that exist in the grain boundaries of the solution heat-treated and quenched specimens constitute the nuclei for the formation or growth of the clumps of "grain boundary gamma" which form during the tempering heat-treatment. These particles must have been precipitated from the solid solution during the water quench from the solution heat-treatment temperature.

Tests were made to determine the effect of quenching speed on the amount of "grain-boundary gamma" precipitated; 1-in. lengths of the bar material were inserted in a blind hole in a block of heat-insulating material. They were then solution heat-treated in the block and the whole assembly quenched in water at room temperature. The exposed end of the rod received the fastest quench and the end shielded by the insulating material was cooled less rapidly. The effects on the microstructure have already been described.

Hardness tests were also made on the material in all conditions. The figures obtained are given in Table I.

The tempering temperature has been shown to affect the bulk of the grain-boundary constituent; the higher the tempering temperature the greater the amount of the "discontinuous" type of precipitate. This is a generally accepted fact and is not confined to the beryllium-copper alloys. The abnormally small amount of "grain-boundary gamma" in the specimen that was temper hardened after cold working may be attributed to the fact that there is a greater tendency for the precipitation to take place on the crystallographic planes with a corresponding reduction of the amount in the grain boundaries. This effect was noticed by Menzen⁶ when examining age-hardening alloys of the aluminium-magnesium type.

Conclusions

The presence of gamma constituent at the grain boundaries would appear to be dependent to a large extent on the physical condition of the crystal interface. Changes in the angle of orientation of the abutting grains cause variations in the amount of precipitate.

It was found that a grain-boundary precipitate existed

even in the solution heat-treated and quenched specimens. With higher solution heat-treatment temperatures less grain-boundary precipitation occurred and less of the bulky "grain-boundary gamma" appeared on precipitation hardening. It was also found that the faster the quenching rate the less precipitate appeared. It is considered that these particles form nuclei for the further growth of the "grain-boundary gamma" on subsequent heat-treatment.

The temperature of the precipitation hardening heat-treatment was found to have a marked effect on the bulk of precipitate in the hardened structure. The higher the temperature the more "grain-boundary gamma" appeared.

Material cold worked after solution heat-treatment and before the final hardening treatment showed far less "grain-boundary gamma" than material which had not been cold worked.

Hardness tests made on this alloy confirmed that the appearance of the bulky "grain-boundary gamma" phase in the structure was accompanied by a drop in hardness. This can be explained by the fact that the amount of beryllium available for hardening the matrix would be lower with increased grain-boundary precipitation.

Messrs. Joshua Bigwood & Sons Ltd.

THE HEATING DIVISION OF MESSRS. JOSHUA BIGWOOD AND SONS LTD., of Wolverhampton, have moved their London office to 41/42, Parliament Street, London, S.W.1 (Telephone: Whitehall 0748). Mr. H. C. Williams is their representative and will be in attendance at this office at all times to deal with technical services, sales, installations and maintenance so far as Bigwood "Unicalor" Stokers and Bigwood "Convectare" Stoves are concerned.

New British Chemical Standards

BUREAU OF ANALYSED SAMPLES, LTD., Middlesbrough, announce two new analytically standardised samples, viz., No. 233 Permanent Magnet Alloy and No. 230 Cast Steel.

The composition of these standards is as follows:—

No. 233 Permanent Magnet Alloy		No. 230 Cast Steel	
	%		%
Nickel	11.22	Nitrogen	0.007
Aluminium	6.98	Nickel	0.143
Copper	5.09	Chromium	0.464
		Molybdenum	0.173
Provisional Figures		Copper	0.085
Cobalt	23.7—	Approx. Figures	
Titanium	0.78	Carbon	0.17
Manganese	0.23	Silicon	0.2—
Alumina	0.025	Phosphorus	0.04
		Manganese	0.05—

The Permanent Magnet Alloy will be useful to chemists for checking accurate determinations for Ni, Al, Cu, etc., in alloys of this kind.

No. 230 Cast Steel has been prepared specially for nitrogen content and for residual metals.

Both standard samples are supplied as usual in bottles of 25, 50, 100 and 500 grms. and each bottle is accompanied by a Certificate of Analyses showing all the co-operating chemists' figures and the average of all.

The Certificate also gives an outline of all the methods employed by each chemist in the analytical standardisation.

Supplies may be obtained either direct from the Bureau or from any of the usual laboratory furnishers.

⁵ Forsyth, King, Metcalfe & Chambers. *Nature*, Vol. 158, p. 875, Dec., 1946.
⁶ Contribution to the question regarding the stress corrosion of aluminium-magnesium alloys. P. Menzen, *Metallwirtschaft XXI*, 1942, No. 35/36, p. 526.

Sinter-Alumina—Part II

Production, Physical Properties and Uses

By Felix Singer,* Dr. Ing., Dr. Phil., M.I. Chem. E., and Hans Thurnauer,† M. Sc.

Metallic oxides, because they comprise one component and one phase only, permit more accurate investigation. For specific purposes these oxides are better than certain orthodox products. In this report the author describes investigations carried out on sintered alumina and explains theoretically the main factors which affect the usefulness of this material, giving particular attention to the chemistry of reaction in the solid phase and to the orientation, growth and general characteristics of the crystallites in sintered alumina in particular. In this, the second part of the report, attention is directed more especially to the production of sinteralumina components, their physical properties and uses. It is stated that the field of application is developing, especially for metallurgical purposes.

WHEN pure refractory oxides were first used for ceramics plasticity was conferred upon the powdered raw material by bonding substances such as clay or organic materials. There are objections to the use of bonding substances: clay forms glassy constituents on firing and the product suffers from the disadvantages of the glassy part, while it is more difficult to obtain gas-tight ware when organic binding materials are used. Count Schwerin's² invention laid the foundation of oxide ceramics. The first material which can be described as sinteralumina, although it was not completely dense, was invented by Dr. Buchner in Heidelberg,²¹ about 1905. In 1912, a patent was granted to the British Thomson-Houston Company, Ltd., on improvements in wear-resisting bodies²² of sinteralumina especially for dies for wire drawing. Another invention in the same direction was the addition of corundum to stoneware bodies by the Deutsche Steinzeugwarenfabrik, Friedrichsfeld-Mannheim. The use of alumina for tools was patented in 1913.²³ Otto Ruff produced pure oxide articles (zirconium oxide) in 1914.²⁴ In about 1925 the Siemens Companies in Siemensstadt, Berlin, developed sinteralumina for sparking plugs. H. Gerdien²⁵ and R. Reichmann developed this new insulating material for sparking plugs. The raw material was pure alumina which was ground finely and the particles suspended in diluted acid. By suspension in the negatively charged medium, the positively charged particles were prevented from flocculating and thus the slip was stabilised for casting. The bodies were then dried and fired. They could be given a final shaping if necessary after drying, as they are very strong, but after firing any further shaping is impossible except by the use of diamond tools.

While Siemens used 99.8% pure alumina²⁶ the Russians²⁷ added mineralisers to the alumina. In the

preliminary investigation AlCl_3 , cryolite ($3\text{NaF} \cdot \text{AlF}_3$), FeCl_3 and $\text{B}(\text{OH})_3$ were tried in amounts varying from 0.5 to 3%. It was found that all products were very similar, regardless of which mineraliser had been used. The best mineraliser is FeCl_3 which reduces the firing temperature to $1,600^\circ\text{C}$. Cryolite is also satisfactory. The finished product is sinteralumina with less than 0.67% impurities and the remarkable high specific gravity 3.9. Further reports²⁸ show that salts of the alkaline earth metals were added to the alumina as mineralisers, 1 to 2% was added. The authors claim that their "Korundis" crucibles surpass the German sinteralumina crucibles.

All ceramic shaping processes can be applied to sinteralumina. These are for example, extruding, dry and semi-dry pressing, plastic moulding, casting and binding with organic binders. So far as pure aluminium oxide is concerned, casting and the addition of organic plasticisers and other organic binders are the most widely used methods. Sinteralumina bodies with a permanent bond are often difficult to cast but suitable for extrusion. Wyoming bentonite presents one of these types of bonds.

Sinteralumina is characterised by its extreme chemical inertness. It is resistant against solutions and melts of alkalis, it shows even a considerable resistance against hydrofluoric acid, and against nearly every acid. It is not attacked by steam at high pressures, (24 hours at 150 atmospheres), or chlorine and carbon dioxide at high temperatures.

R. Winzer,²⁹ in 1932, studied the corrosion of pure oxide ware by various chemical agents. He concludes that sinteralumina at $1,700^\circ$ to $1,800^\circ\text{C}$. is resistant to all gases and vapours except fluorine. Among liquids, acids and alkalis at their boiling point and after a 6-hour treatment do not produce a corrosion greater than 0.02% of the original weight of the tested article.

Only 40% hydrofluoric acid causes a weight loss of 0.08%. Metallic melts, except lithium, do not attack sinteralumina vessels. In oxidising atmospheres, however, manganese, iron and chromium corrode the material. Most fused alkaline oxides and hydroxides have no effect, but lead, manganese and iron oxides attack sinteralumina, and so does tungstic anhydride.

*Consulting Ceramist, Keramos House, 46, Castlemaine Avenue, South Croydon, Surrey.

†Vice President, Director of Research, American Lava Corporation, Chattanooga, Tenn.

19 Emil Podszus, "Sinterung." *Sprechsal*, 1917, No. 8/12, vol. 50.

20 E. Ryschkewitsch, "Die plastische Deformierbarkeit spröder Körper." *Glastechnische Berichte*, 20 (1942), p. 166.

21 Engelhorn, "The Treatment of Corundum for the Manufacture of Ceramic Compositions." Brit. Patent 15539/1906.

22 British Thomson-Houston Co., "Improvements in and Relating to Wear-resisting Bodies and in Methods of Manufacturing the same." Brit. Pat. 4887/1912.

23 Allgemeine Elektrizitäts Gesellschaft Berlin, "Werkzeuge, wie Ziehsteine, für die Metallbearbeitung und Verfahren ihrer Herstellung." German Pat. 284808 (1913).

24 Otto Ruff, "Über die Herstellung feuerfester Geräte." *Sprechsal*, 1914, No. 24.

25 H. Gerdien, *Z. techn. physik.*, 12 (12), 586-90, 1932, abstracted in *Feuerfest*, 9 (1), 13, 1933.

26 Siemens and Halske, "Sinter Corundum Products." *Siemens Z.*, 14 (7), 255-56, 1934, abstracted in *Ceram. Abs. J. Am. Cer. Soc.*, Feb. 1935, p. 41.

27 D. S. Beljankin and N. A. Filonenki, "Influence of Mineralisers on the Formation of Sinter alumina." *Doklady Akademii Nauk U.S.S.R.*, 2, 1935 (2), 146-50 (Russian), 150-53 (German).

28 L. I. Kaz and G. L. Jefremow, "Korundis, a new high quality ceramic material." (Russian) *Savodskaja Laboratorija*, 5 (10), 1,274-75, 1936.

29 Robert Winger, "Korrosions bestimmungen an Geräten aus reinen Oxyden." *Angewandte Chemie*, 45, 429, 1932.

Among fused salts only fluorides, some silicates and calcium chloride are harmful. As expected, fused minerals containing fluorine damage sinteralumina. Asbestos is the only other mineral, among those tested, which attacks sinteralumina. This extreme chemical resistance is not attained by other ceramic materials.

Among the physical properties, the high melting point of 2,050° C., the complete gas-tightness at 1,700° C., the great hardness (9 Mohs) and the excellent mechanical properties, which are retained at high temperatures, are outstanding.

"Sintox" of Messrs. Lodge Plugs Ltd., Rugby, (1944)

PHYSICAL PROPERTIES OF SINTER ALUMINA.	
Ultimate Strength, lbs./in. ²	10,800
Young's Modulus, lbs./in. ²	46.7×10^6
Compression Strength, lbs./in. ²	240,000
Modulus of Rupture, lbs./in. ²	48,400
Specific Gravity	3.65
Co-efficient of Expansion:—	
0° to 300° C.	6.2×10^{-6}
300° to 800° C.	8.25×10^{-6}
Thermal Conductivity, C.G.S. Units	0.54
Specific heat, C.G.S. Units	0.175 at 25° C.
Dielectric Strength 50 cycles KV./Cm.	480
Impulse	820
Dielectric Constant 1 m.c.	9.6
1,000 cycles	10.0
Power Factor, 1 m.c.	0.0006
1,000 cycles	0.0080
Volume Resistivity, Ohm. Cm., 14° C.	10^{16}
100° C.	2×10^{15}
200° C.	4×10^{14}
300° C.	3×10^{13}
Temperature Coefficient of Capacitance	$+125 \times 10^{-4}$
Per ° C. at 1 m.c. (10° to 65° C.)	

Thermally, the conductivity is exceptionally high for ceramic materials. It varies from:

0.087444 B.Th.U./h./sq. ft./° F./inch at 62.6° F., which is about sixteen times better than that of porcelain, to:—

0.0255045 B.Th.U./h./sq. ft./° F./inch at 1.472° F.

Resistance against heat shock is better than that of sillimanite, porcelain and steatite.

Electrically, sinteralumina shows an exceptionally high electrical resistance at high temperatures. The specific resistance varies between $12,000 \times 10^9$ ohms at 360° C. to 0.35×10^9 ohms at 860° C. At 400° C. the specific resistance of sinteralumina is about 100,000 times greater than that of porcelain.

Judging from experience collected so far, sinteralumina does not show the phenomenon of fatigue, which can be observed in porcelain. After repeated heating and cooling the latter shows ageing and may crack. This is due to the strains set up in porcelain, which is a heterogeneous material when the various constituents—crystals and glassy matrix—expand according to their own specific coefficient of expansion.^{30, 31} As good sinteralumina should be composed of one substance only, this disadvantageous property of heterogeneous ceramics is avoided.

These properties make sinteralumina an almost ideal material for a whole variety of products.

Laboratory equipment of sinteralumina stands up to chemical and thermal stresses extremely well. As the vessels can be produced with very thin walls their resistance to heat shock is increased and they can be used instead of platinum ware at a very much smaller cost. It has been on the market since the early thirties.

For example, in 1932 Hermann Salmang and Nikolaus Planz³² described crucibles of alumina and of mixtures

of alumina and magnesia for investigation of metals, oxides and silicates.

In 1934, Donald Turner³³ still found it necessary to produce some of the refractory crucibles required in the course of metallurgical research at the National Physical Laboratory. He made pure sinteralumina crucibles by slip casting. They proved entirely satisfactory for the melting of iron. The exacting requirements of Vaughan H. Stott,³⁴ also at the National Physical Laboratory, in 1937, necessitated the production of part of their needs of refractory ware in the Laboratory. A method for producing sinteralumina were only requiring the limited facilities offered by the laboratory is described by Heinz Schmellenmeier in 1943.³⁵ John G. Thomson and Manley W. Mallett³⁶ in 1939, studied slip casting methods for making refractory oxide crucibles. The principle of slip casting is simple: the acid slip is poured into a plaster of Paris mould where it gradually solidifies as the gypsum absorbs the water from the slip. In practice, however, the authors found it necessary to control closely certain factors which were discussed for clayware by F. H. Hall.³⁷ During the war, crucibles for atomic research were made of pure oxide ceramics.³⁸ Beryllia was found the most suitable material.

Sinteralumina was originally intended as insulating material for sparking plugs.³⁹ It is ideally suited for this purpose. Its high heat conductivity assures that the insulating material itself conducts away the heat generated, its high electrical resistance at high temperatures allows its use at the highest temperatures reached in combustion motors, its resistance to thermal shock enables it to withstand the large and very frequent changes in temperature, and lastly its chemical inertness guards it against soot and the residues of anti-knock chemicals. During the war, the sparking plugs of all Allied aircraft were made of English sinteralumina, and President Roosevelt referred to them as a vital article supplied in the Reverse Lend-Lease Agreement.⁴⁰ The Russians⁴¹ used sparking plugs made of approximately 90% alumina. They are characterised by some glassy matrix and therefore have a heterogeneous structure. One of their products was composed of 95% alumina, the oxides of silica, calcium, magnesium and ferric oxide made up the remaining 5%.

German aircraft were also equipped with sinter alumina sparking plugs made by Siemens.⁵¹ They produced 200,000 sparking plugs per month in 1944.

The smooth surface of sinteralumina and its great mechanical strength allow it to be used as thread guides in the textile industry and as dies for wire drawing.⁴²

Corundum base bodies are used in the production of ceramic gauges.⁴⁸ Owing to their great hardness they are very resistant to abrasion and are better than steel gauges. They were used during the war in testing steel cartridge cases and it was found that 350,000

34 Vaughan H. Stott, "Gas-tight Sintered Alumina Ware." Trans. of the Cer. Soc. (England), **37**, 346, 1937/8.

35 Heinz Schmellenmeier, "Eine einfache Methode zur Herstellung fester keramischer Formteile für Temperaturen bis zu 1,800° C." *Z. f. techn. Physik*, 1943 (No. 91), 217.

36 John G. Thomson and Manley W. Mallett, "Preparation of Crucibles from Special Refractories by Slip-casting." Research paper R.P. 1256, 1936. Nat. Bureau of Standards, Washington, D.C.

37 F. H. Hall, "The Casting of Clayware." *J. Am. Cer. Soc.*, **13**, 751, 1930.

38 Anon., *Ceramic Industry*, **46** (1), 56, January, 1946.

39 Hans Kohl, "Sinterkorund, ein neuer keramischer Werkstoff aus reiner Tonerde." *Ber. d. Deutschen Ker. Ges.*, **13**, 70, February, 1932.

40 White Paper, Cmd. 6570, H.M. Stationery Office, *The Times*, November 25th, 1944, p. 8, column 3.

41 D. S. Belankin and V. V. Lapkin, "The Sinter Corundum and the High Grade Alumina Ceramics in Modern Aeronautical Engineering." *Bull. of the Academy of Sciences of U.S.S.R. Div. of Technical Sciences*, No. 6, 1944.

30 Felix Singer, "Alternde und nicht alternde keramische Massen." *Keramische Rundschau und Kunstkeramik*, **36**, 167, 183, 216, 1930.

31 Felix Singer, "Sanitary Vitreous China." Transactions of the Ceramic Society, (England), **XI**, p.19, April, 1941.

32 Hermann Salmang and Nikolaus Planz, "Herstellung Schlackenbeständiger Geräte aus Magnesia und Tonerde." *Archiv für das Eisenhüttenwesen* **6** (8), 341-345, 1933-35.

33 Donald Turner, "Special Refractories for Metallurgical Research at High Temperatures." Trans. of the Cer. Soc. (England), **33**, 33, 1933/4.

pieces could be measured by one ceramic gauge, while one steel gauge could only be used for 15,000.

The hardness of sinteralumina also makes possible its use as mortars, stamps and grinding balls.²⁰

Sheaths for platinum and platinum-rhodium thermocouples are made of sinteralumina. In reducing atmospheres, particularly, they are an improvement on silicate containing compositions, as the latter may form silicides which impair the E.M.F. characteristic of the thermocouple.⁴²

An interesting use for sinter alumina has been patented since 1912⁴³ but not yet used on a large commercial scale, namely its use as a cutting tool for metals, especially as tool tips.

Research into the use of sinteralumina is continuing and satisfactory results have been achieved in some cases. Sinteralumina tools for cutting plastics are superior to steel tools, although boron carbide is better than alumina.⁴⁴ Ceramic tools are supplanting steel tools for cutting wood, glass, stone and concrete. A mixture of alumina and chromium oxide has been tried as a composition for ceramic tools.⁴⁵

The production of tools from sinteralumina, for instance, for turning is considered an important use of this ceramic material.⁴⁶ The hardness of tungsten carbide is not higher than that of Al_2O_3 , especially ruby. The mixed crystal of Al_2O_3 is harder than each of the components and therefore E. Ryschkewitsch⁴⁷ has suggested to use ruby for such tests. No extensive research has yet been conducted to determine the maximum hardness and other tensile properties in relation to the concentration of Cr_2O_3 . About 2 to 2.5% Cr_2O_3 is contained in the sintered ruby.

This sintered ruby has proved itself in various tests conducted by E. Ryschkewitsch as a suitable material for cutting tools, for instance, for the turning of Al and its alloys (silumin) for Cu-alloys, for plastics, for coal and also for Fe alloys. An important pre-requisite is a lathe free of vibrations. The cutting speeds should be very high, the depth of cut should be small. The importance of ceramic tools is further revealed by the fact that in 1939 Germany produced hard metal tools (carbide tools) valued at 100,000,000 marks.

Tools made from sinteralumina are produced on a laboratory scale to the perfect satisfaction of all requirements. However, it is not known that the transition to a commercial scale of production has been achieved yet. It seems to be difficult to obtain a consistently high quality of the final article. Sinteralumina can be used as lining in high temperature electrical or gas-fired furnaces. Resistance to abrasion allows the use of sinteralumina as nozzles in blasting or spraying machines.

In Germany, starting in 1940, attempts were made to utilise ceramic compositions of the refractory oxide type as turbine blades.⁴⁹ At that time the supplies of alloys, which were used in the Allied Countries for turbine blades had been almost exhausted in Germany.

In 1944, when the acute shortage of nickel and chromium, both necessary for making high temperature steels, was realised L.F.A. (Luftfahrtforschungsanstalt) was ordered to investigate the utilisation of ceramic materials in place of the steels. The most promising series of compositions consisted of varying proportions of sinteralumina and iron, and was suggested only a few months before the German collapse. Its qualities were not proved. The blade shapes were obtained either by moulding in a plaster mould or by extrusion through a nozzle of the desired blade profile. The blades could be used in gas turbines at temperatures not exceeding 700°C. Due to the low ultimate tensile strength of ceramic materials, they are not suitable for turbine blades mounted externally on a rotating drum or wheel. G. H. de Witt considers that if research had continued for another year and an adequate supply of raw materials had been available L.F.A. probably would have developed stationary turbine blades suitable for operation up to 1,200°C.

The Maschinenfabrik Augsburg-Nürnberg M.A.N. (Nürnberg) spent six years of research on the use of ceramic materials for gas turbine blades and obtained entirely negative results. No successful runs were made and their target did not compare favourably with values in use with metal blades both cooled and uncooled.⁵⁰

M.A.N. (Augsburg) had a turbine blade made by E. Ryschkewitsch by the slip casting method. This was the first ceramic turbine blade, produced at the beginning of the war.⁵¹

From this survey it can be seen how an entirely new branch of ceramics spread its products in less than twenty years to factories and laboratories where highly resistant apparatus is necessary. The scope of ceramics was widened enormously by the invention of pure oxide refractories. Scientific study of these one-component systems will yield information which will benefit the whole industry by explaining some of the fundamental processes involved in the making of ceramics.

At the moment, it can be assumed that several hundred thousand pieces of sinteralumina articles, namely sparking plugs, sand-blast nozzles, laboratory ware, are manufactured commercially per day and it seems probable that this figure will increase very considerably. The field of application of sinter alumina will be widened also, especially for metallurgical purposes, such as electrical insulators, cutting tools, turbine blades and dies for wire-drawing, etc.

Corrigenda

Sinteralumina, Part I.

The following corrections should be noted to the above article by Felix Singer, Dr. Ing., Dr. Phil., M.I.Chem.E., and Hans Thurnauer, M.Sc., the first part of which was published in the September issue of this *Journal*:

Page 239, 12th line from top of 2nd column "SiC or B_4C " should read " SiC or B_4C_3 ."

Page 241, 2nd line from top of first column " $5.88 \times 10^4 \text{ kg/cm}^2$ " should read " $3.88 \times 10^4 \text{ kg/cm}^2$."

Footnotes: ⁴A. King and H. Fromherz should read A. King and H. Fromherz. ¹⁰ *Zeitschrift für angewandte und Mineralchemie*.

42 D. Kirby, "Pure Oxide Refractories," *Metallurgia*, **30** (176), 65-69, 1944.

43 British Thomson-Houston Co., London, "Improvements in and Relating to Wear-resisting bodies and in Methods of Manufacturing the same," Brit. Pat. 4887/1912.

44 W. Osenberg, "Machining of Plastics with Ceramic Tools," *Maschinenbau Der Betrieb*, **17**, 127-130, 1938. *Plastics*, **(111)**, (90), 509-514, 1944, translated from.

45 Anon., "Substitutes for Metals," *Chemical and Metalurgical Engineering*, 132-12, December, 1942.

46 Martin Fleischmann, U.S. (Ord.), "Electro Schmelzwerke A.G. Kempen, Allgau, Bavaria," Intelligence Report, Item No. 21, File No. XXVI-35, London, H.M. Stationery Office.

47 Eugen Ryschkewitsch, "Ceramic Cutting Tool," United States Patent 2,270,607, January 20th, 1942.

48 Robert Twells, "Ceramic Gauges of Abrasion Resisting Compositions," *Bull. of the Am. Cer. Soc.*, **23**, 408, November 15th, 1944.

49 G. H. de Witt, R.C.A.F., "Development of Ceramic Materials for use in Gas Turbine Engines," Intelligence Report, Item No. 5, File No. XXVI-9, H.M. Stationery Office.

50 S. T. Robinson, U.S.N.R., and R. S. Sproule, R.C.A.F., "Interview of Prof. Dr.-Ing. Emil Sorensen, Maschinenfabrik Augsburg, Nürnberg A.G. Intelligence Report, Item No. 5, File No. XXVII-20, H.M. Stationery Office.

51 S. S. Kistler, T.I.L.C., "Refractories in Turbine Blades plus Miscellaneous Applications," Intelligence Report, Item No. 1, 18, 21 and 25, File No. XXXI-

The Institute of Metals

Annual Autumn Meeting held in Glasgow

THE 39th annual autumn meeting of the above Institute took place at the Institution of Engineers and Shipbuilders, Glasgow, on September 23rd to 25th, by invitation of the Scottish Local Section of the Institute. A very full and interesting programme had been arranged which, in addition to the business meeting, included an official reception, technical meetings, and visits to neighbouring works: interesting visits were also arranged for the ladies who accompanied members at this meeting.

The meeting was officially opened at 8 p.m. on September 23rd, when Sir James Weir French, D.Sc., president of the Reception Committee occupied the Chair. It was, he said, his pleasant duty to welcome members and their ladies to the City of Glasgow. He regretted the absence of the Lord Provost, who unfortunately was away from town, but Deputy Lord Provost, Councillor Hood, was present and welcomed the visitors in the name of the City. Professor R. Hay, a Professor of Metallurgy at the Royal Technical College, on behalf of Sir Hector Hetherington, Principal of Glasgow University, welcomed the visitors on behalf of the academic bodies of the City. He reminded us that, in 1910, the Institute, then in its second year, came to Glasgow, and the then Principal of Glasgow University, Sir Donald Macalister, welcomed the Institute in the University buildings. His predecessor and Past President of the Institute, Dr. Desch, played a very important part in that early meeting, out of which arose the Scottish Local Section. Since 1910, Professor Hay continued, many things have happened, and amongst them the development of metallurgy from an art to a science. During that period the University has founded a degree which in Scotland is not called the degree of metallurgy but the degree of applied chemistry. Although this degree is of comparatively recent foundation, metallurgy has been taught in Glasgow since 1886, when the chair was founded at the college.

While it may be the case that in Glasgow research laboratories are probably more allied to ferrous metallurgy, nevertheless, these laboratories are well aware of the importance of developments in the non-ferrous world. In fact, the fundamentals of metallurgy are universal, and it cannot be too often emphasised that metallurgy is one large subject, a subject of many facets. Whether we call them physical metallurgy, process metallurgy, ferrous and non-ferrous metallurgy they are all one and the same thing, and it is important that all these facets should be studied and recognised.

A further welcome was extended by Mr. W. H. Marr, President of the Glasgow Chamber of Commerce, on behalf of trade and commerce, in which he hoped that, for those who had not been to Glasgow before, it would prove a pleasant visit, while those who had been before would find many new things to interest them and many pleasant memories as a result of the visit.

The President of the Institute, Colonel P. G. J. Gueterbock, in responding expressed the thanks and gratitude of the Institute for the arrangements made to

receive members and their ladies, and in particular the Deputy Lord Provost, Professor Hay and Mr. Marr for the kind and gracious words in which their hospitality was couched.

Autumn Lecture

Sir James Weir French then vacated the Chair, which was taken by the President of the Institute, Colonel P. G. J. Gueterbock, C.B., D.S.O., M.C. who introduced Professor G. Wesley Austin, O.B.E., M.A., M.Sc., Professor of Metallurgy at Cambridge University and a Vice President of the Institute, who gave the Autumn Lecture on "The Metallurgical Resources of Scotland." A vote of thanks to the Autumn Lecturer was subsequently proposed by Mr. A. Craig MacDonald, Vice-Chairman of the Scottish Local Section, and seconded by Mr. A. B. Graham, Chairman of the Scottish Local Section, was carried with acclamation and the evening meeting terminated.

Nomination of Officers for 1948-49

The meeting was resumed the following morning, the President occupying the Chair, when the Minutes of the previous General Meeting were taken as read. The President then announced that the following officers were due to retire from the Council at the March, 1948 meeting and will not be eligible for re-election:—

President: Colonel P. G. J. Gueterbock.

Vice Presidents: Mr. Roosevelt Griffiths and Dr. J. L. Haughton.

Ordinary Members of Council: Mr. W. H. Henman and Mr. Stanley Robson.

The Council has made the following nominations to fill the vacancies and to confirm two appointments made by the Council to fill vacancies occurring since the last Annual General Meeting:—

President: Sir Arthur Smout, J.P.

Vice-Presidents: Dr. S. F. Dorey, Mr. A. J. Murphy, M.Sc., and Mr. H. S. Tasker, B.A.

Hon. Treasurer: Mr. W. A. C. Newman, B.Sc., A.R.S.M., A.R.C.S.

Ordinary Members of Council: Mr. D. F. Campbell, M.A., A.R.S.M., Mr. A. Dando, Mr. T. M. Herbert, M.A., Mr. D. P. C. Neave, M.A. and Mr. A. R. Powell.

Mr. H. H. A. Greer, J.P., Elected a Fellow

It is the custom of this Institute from time to time to confer the distinction of Fellowship on a member who has rendered signal service to metallurgy and particularly to the work of the Institute. The number of these Fellowships is limited to twelve, a very small number, it is thus one of the highest honours this Institute can confer on a member.

The President announced that the Council decided to confer this honour on Mr. H. H. A. Greer, J.P., who is well known in the metal trades, especially in Scotland, and has been connected with the industry for over fifty years. He is an original member of the Institute

and took a large part in the formation of the Scottish Local Section in 1918, remaining a member of its Committee from its formation to 1944. He was a member of the Council of the Institute from 1928 to 1936 and occupied many official positions for the Scottish Section. In the early days of the formation of the British Non-Ferrous Metals Research Association, Mr. Greer was its only member in Scotland and acted as its Hon. Correspondent in Scotland. He is a member of many associations and societies and is a Justice of the Peace for the County of Ayr. He has led a busy life, not only in his profession, but in public service and in other bodies besides the Institute. The President had every confidence that members would endorse the action of the Council in recognising his great public service by making him a Fellow of the Institute.

Mr. Greer, in responding, expressed his great appreciation and thanks for the signal honour conferred upon him. He regarded it as an honour not only to himself, but to the Scottish Section of which he was particularly proud. He reminded members that the Section had had some distinguished men as Chairman. Such men as Dr. Desch, Dr. Andrew, Dr. Hay and Professor Wesley Austin were mentioned. He made a plea for a much larger attendance at Sectional meetings, particularly of younger men.

TECHNICAL SESSIONS

The remainder of the morning session was devoted to the presentation and discussion of two papers—"Surface Effects during the Annealing of 70-30 Brass" and "The Centrifugal Casting of Copper Alloy Wheels in Sand Moulds." On the morning of the third day, the following were discussed: "Frictional Properties of some Lubricated Bearing Metals"; "The Variation in Corrosion Properties over Two Magnesium Alloy Sheets"; "The Corrosion of Some Magnesium-Base Alloys (High and Normal Purity) in Contact with Other Metals"; and "Note on the Quantitative Implications of Hanawalt's Theory of Corrosion of Magnesium-Base Alloys." In the following notes summaries of these papers are given together with condensed reports of the discussions on them.

SURFACE EFFECTS DURING THE ANNEALING OF 70-30 BRASS.*

By IVOR JENKINS, M.Sc.

COPPER-ZINC alloys, and more especially those containing more than approximately 15% zinc, are difficult to anneal fully without surface discoloration. The difficulties, in the main, are associated with the marked susceptibility of the alloys to oxidation and staining by oxygen-bearing and sulphurous gases, and to the comparatively high vapour pressure of zinc in brass at normal annealing temperatures. Probably the major difficulty associated with the annealing of brass is that due to the loss of zinc by evaporation, which, in the absence of barrier films of oxide, attains an appreciable rate at temperatures above 450°C. The loss of zinc results in the enrichment of the surface of the alloy in copper, destroying the normal brass colour and giving rise to superficial roughening and etching. The defect occasionally met on annealed brass, and known as "red stain," has been attributed to local zinc loss during the annealing treatment.

The bright annealing of brass, more especially cold rolled strip in coils, has engaged the attention of many workers, particularly during the last 20 years, when the industrial development of controlled atmosphere processes for the heat treatment of metals has been very rapid. Various techniques have been advocated, but the limited success achieved on an industrial scale only serves to indicate the difficulties attending the translation of a successful laboratory technique to practical conditions. In view of the susceptibility of brass to staining, it is necessary that in developing a bright-annealing process, a protective atmosphere should be used which is free from oxidising and sulphur-containing gases. Cracked ammonia, containing 75% hydrogen and 25% nitrogen and produced by the catalytic dissociation of synthetic, anhydrous ammonia, is probably the only industrial controlled atmosphere which meets these requirements.

The annealing processes which have been developed have been concerned with the prevention of excessive zinc volatilisation from the brass, and the elimination from the annealing container of any gases which would give rise to staining. Saturation of the annealing atmosphere with an equilibrium concentration of zinc vapour or annealing in cracked ammonia in a sealed container have been suggested as methods for preventing excessive zinc loss, while the introduction into the annealing pot of readily oxidisable metals has been proposed as a means of eliminating staining due to occluded gases. For material of light gauge, which can be coiled very tightly to give a solid coil wall, bright annealing of all but the outer turns of the coil has been claimed, again using a protective atmosphere of cracked ammonia. This technique is limited to strip of less than approximately 0.010 in. thick and it is possible that difficulties might arise owing to the "sticking" of adjacent turns of the coil.

The present paper describes work carried out with the object of assessing the various factors influencing the surface condition of brass when annealed in the form of coils of strip, with the ultimate aim that such data might form a useful basis for the development of an industrial bright-annealing process. The material used throughout the experimental work was commercial quality 70-30 brass, supplied in the form of hard-rolled strip 3 in. wide and 0.022 in. thick. As a result of the investigation it is concluded that annealing under a pressure of cracked ammonia, while restricting the loss of zinc from brass, does not prevent surface oxidation. The source of the oxidation is primarily the gases evolved from the brass itself. Gas extraction tests under high vacua have shown the gas content to be of the order of 0.45 c.c. per c.c. of metal, the gas, in the main, consisting of carbon dioxide with smaller concentrations of carbon monoxide and hydrogen. It is shown that the bulk of the carbon oxides are concentrated near the surface of the strip and are probably associated with contamination during rolling.

Small-scale tube experiments on single specimens of 70-30 brass at temperatures between 400° and 600°C. *in vacuo*, in a static atmosphere and in a flow of cracked ammonia, indicate that in the two latter cases surface-staining results from the evolution of gas from the metal. Annealing *in vacuo* removes this source of staining, and the metal surface is etched due to an appreciable loss of zinc from the surface, which assumes a coppery appearance. Annealing in a static atmosphere

* Jour. Inst. M. July, 1947, 641.

or a flow of cracked ammonia results in some zinc loss, with surface staining, but even at 600° C. the brass does not lose completely its yellow colour.

By a combination of a vacuum treatment followed by an anneal at a higher temperature in a static atmosphere of cracked ammonia, specimens have been produced free from surface staining and having an etched appearance. The final treatment in the static atmosphere permits of the diffusion of zinc to the surface of the brass to replace that previously lost during the vacuum treatment, and the alloy tends to regain at the surface its original composition and colour.

This double process has been successfully applied to the bright annealing of small coils of degreased or dry-rolled strip in a small pot-type furnace. The vacuum treatment is continued up to 500° C. at a pressure of 4 mm. of mercury and continuation of the anneal up to 550° C. in the static atmosphere gives satisfactory bright annealing. With material rolled in oil, an almost imperceptible stain remains in the centre of the strip. This has been overcome by separating the individual coil turns by brass wire spacers, and treating the spaced coil by the above technique.

Experiments on the effect of annealing atmosphere of different densities upon the loss of zinc from 70-30 brass show that the rate of loss decreases with increasing density. In this respect, an atmosphere produced from hydrogen saturated with methanol vapour, has given most encouraging results, from the point of view of non-oxidation and the restriction of zinc evaporation. It is considered that a combination of vacuum treatment and a final anneal in this type of atmosphere may provide a process for the bright annealing of brass on a commercial scale.

From the results obtained on the small-scale vacuum experiments, data have been calculated for the diffusivity constant of zinc in 70-30 brass, within the temperature range of 400°-600° C. Typical values of the diffusion constant D , are:—

$$\begin{aligned} D &= 6.8 \times 10^{-14} \text{ at } 405^\circ \text{C.} \\ &= 1.01 \times 10^{-11} \text{ at } 500^\circ \text{C.} \\ &= 1.38 \times 10^{-10} \text{ at } 600^\circ \text{C.} \end{aligned}$$

The activation energy for the process, calculated from the diffusion data is 46,000 cal./gram-atom.

Discussion

DR. C. E. RANSLEY, in a written contribution to the discussion read by DR. F. A. CHAMPION, commented on that part of the paper dealing with the diffusion of zinc in α -brass and called attention to the uncertainty of diffusion data derived from measurements of the type described by the author. He cited several objections to the use of evaporation technique for this purpose.

On the assumption that similar specimens were used for the gas-content determinations as for the diffusivity measurements, a rough calculation of the contribution of the evolution of surface gases to the total loss of weight of the specimen shows that the loss in half an hour, at about 400° C., due to surface gases is 0.02 mg., whereas the total loss amounts to only 0.033 mg. No correction seems to have been made for this, so that the value of the diffusivity constant D at 405° C. is probably in error to the extent of considerably more than 50%.

The author's diffusion experiments were carried out at a residual gas pressure of 3 mm. of mercury, but he mentions in the paper that incipient oxidation occurred when the pressure was greater than 6-8 mm. The margin of safety is

therefore, not large, and I would suggest that the low-temperature line represents zinc loss through a slightly contaminated surface, which requires a higher energy of activation than is necessary above 500° C., where the contamination is either unimportant or does not take place.

DR. A. G. QUARRELL congratulated the author and said that those concerned with the practical problems of the annealing of brass will be interested in the suggestion that the work may lead to a satisfactory, if somewhat revolutionary, method of bright annealing brass. This process is made difficult by the relatively high vapour pressure of zinc at the normal annealing temperatures and, because of this, a static atmosphere and a minimum of idle furnace space are necessary if the losses are to be reduced to a sufficiently low zinc value for practical purposes. If a static atmosphere is used, the annealing pot must be adequately sealed from the atmosphere, and therefore can easily be made suitable for vacuum work. He felt that some may have misgivings at the suggestion that vacuum conditions should be used in the early stages of bright annealing, but considerable strides have been made in vacuum technique in recent years and the production of vacua of the order of 4 mm. of mercury and a temperature of about 500° C. should present little difficulty, at least in the case of batch furnaces.

The author refers to saturation of the annealing atmosphere with an equilibrium concentration of zinc vapour. As he indicates, one would expect considerable difficulty in obtaining such conditions, and it would be interesting to know whether he has ever tried this method and, if so, with what success.

One of the most interesting features of the paper is the light which it throws on the effects which rolling lubricants may have during subsequent annealing. It has been realised for a long time that rolling lubricants remaining on the metal may affect the nature of the scale subsequently formed, but he believed this to be the first time that anyone has reported work which indicates that it is not possible to eliminate such effects by an adequate degreasing process. It seems likely that the surface gas content of the brass strip will vary with the nature of the rolling lubricant and, therefore, it seems that some progress should be possible by paying attention to the nature of this lubricant. It would be interesting to know whether the pick-up of harmful impurities could be avoided by the use, for example, of silicone oils. They are not an economic proposition at the moment, but the information would be interesting. It might also be of interest to try to develop a rolling lubricant which would lead to a heavy annealing atmosphere due to residual rolling lubricant on the metal. If we could devise a rolling lubricant which on decomposition gave up a suitable vapour, the loss of zinc might be reduced.

There is considerable divergence of view on what constitutes a good rolling lubricant from the mechanical point of view, and I suggest that the time has come for the metallurgist and the oil technologist to get together to rationalise the position. In doing so, they might well pay attention to some of the points raised in this paper.

If the surface gas content referred to by the author is due to impurities being rolled in, the effect should apply in the case of other copper-base alloys; yet it is believed there is no difficulty in the bright-annealing of, for example, tin bronzes. He asked if the author had any idea whether this is due to the fact that there is no reaction between CO_2 and the tin bronze? It seems unlikely. Or because the oxidation product in this case is a transparent continuous film?

Mr. R. CHADWICK found the paper extremely interesting and full of ideas. He thought those interested in the possibilities of bright-annealing the brasses commercially, would be more interested in a process using cracked and burnt ammonia than in one using simply cracked ammonia, because of the much smaller cost. He believed it quite feasible now to produce commercially cracked and burnt ammonia which has more than 90% nitrogen content and only a very small amount of hydrogen, and which is virtually completely free from oxygen and water vapour.

The remarks of Dr. Quarrell he thought raised possibilities with regard to the surface films of contaminants. The author says nothing about the nature of the rolling oil. Possibly he obtained commercially-rolled brass, and therefore has no data available; but it would add to the value of the paper if some analysis of the rolling oil could be quoted. It would be quite feasible commercially, to roll in a sulphur-free lubricant. Another possibility arising out of Dr. Quarrell's suggestions, is that the oil should be dealt with so that it would give off methanol. If that could be done, it might be the solution; but in view of the volatility of that material it is doubtful. However, something which would give off aldehyde or polymerised formaldehyde might be of value. At any rate, there appear to be several possibilities in that direction.

Mr. D. C. G. LEES thought some results in the paper of interest in the casting of brass and asked whether the author had examined any pieces of cast 70-30 brass. It is generally asserted that brasses do not suffer from hydrogen porosity, in that the vapour pressure of zinc over the molten metal precludes the possibility of hydrogen retention; yet gas extracted from samples given in the paper, from which outer layers were removed, contain a large amount of hydrogen—something of the order of 80%.

Dr. L. B. PFEIL, O.B.E., regarded the paper as a very high-quality effort. He interpreted the author's results as indicating that in due course the practical man will turn to strip annealing not in coil but in a continuous process, and will go to higher annealing temperatures and extremely short times, using a furnace which has a very small volume, so that very small zinc losses are required from the strip in order to bring the zinc loss down to zero. Alternatively, of course, the reference made to Robiette's proposals might be developed, and allow us to make use of an atmosphere in which the partial pressure is raised in zinc, so that the strip going through the furnace does not need to lose zinc. He hoped the author and his colleagues will go on working on this subject, and will give us in due course, the benefit of their further work. It is very important indeed nowadays. Unless the strip produced has a good surface finish, polishing is necessary in the case of many of the articles produced from the strip; and labour for the polishing of metal articles is in short supply.

Mr. W. A. BAKER referred to a statement by the author that an atmosphere containing methanol, either alone or admixed with another mutual atmosphere, has the effect of reducing oxidation to negligible proportions and asked if methanol alone is a remedy for the problem. The author suggests that possibly the dissociation of methanol to liberate nascent hydrogen may be responsible for the negligible oxidation. Mr. Baker found it difficult to follow this argument because, even if nascent hydrogen is liberated, the moment the zinc oxide is reduced steam is liberated, and if the pressure of steam is sufficiently high the process will reverse again.

In Table I is given the gas content obtained by extraction from the surface of brass specimens, and figures are reported

in terms of the oxides of carbon, and hydrogen. Apparently these gases were extracted in a system maintained at 10^{-6} mm. of mercury, in which case, if the brass strip contained zinc oxide and carbon rolled into the surface, the two could interact to yield the oxides of carbon. Mr. Baker suggested that the quantities of carbon oxides obtained by that technique might be substantially higher than the actual quantities of these oxides which would be evolved when the material was heated under high pressures.

Mr. H. H. SYMONDS said that in view of the major effect of hydrogen content in the brass its elimination at an early stage in the manufacture would appear likely to be advantageous, at least when the strip is intended for subsequent cold-rolling. Probably the use of vacuum and cracked ammonia techniques for the first anneal after initial breaking down might produce strip which would respond more satisfactorily to annealing at thinner gauges. In this connection, he asked whether this gas extraction can be applied to material of greater thicknesses, in view of the very short time for de-gassing the 0.022 in. material. Furthermore, has the author any information on the response of 0.022 in. strip to a controlled anneal when the strip ingot has been degassed in that way?

The increased hydrogen percentage obtained from levels further from the surface seems to be significant, since it appears that reduction of the surface oxides by this hydrogen permits the evaporation of zinc at a more rapid rate. In this connection, apparently a slightly oxidising atmosphere would be more desirable. That adds emphasis to the desirability of the elimination of gases at an early stage in the strip manufacture.

Mr. J. H. JONES suggests that many papers would be improved if there was an addendum presenting and discussing the particular industrial interest and application of the more scientific data contained in the paper itself. He asked the author if vacuum annealing is really necessary; would not an atmosphere of an absolutely inert gas, free from carbon monoxide and these other gases, meet the case, instead of all the practical complications of vacuum annealing? Instead of the complicated vacuum process, would not a really pure nitrogen gas give similar effects, or effects quite as good.

Reply by Mr. Ivor Jenkins

Some of the points raised by Dr. Ransley involve some mathematics and will be replied to in writing, but Mr. Jenkins said he was aware of the limitations of the method used in determining diffusivity by the technique described; the data was submitted merely as an indication of the freedom of the brass surface from oxidation during the vacuum experiments. With regard to Dr. Quarrell's various points, Mr. Jenkins said that the production of a vacuum on an industrial scale in a bright-annealing plant is not at all difficult. He cited some tests on an industrial scale and mentioned an annealing container carrying a charge of about 30 cwt. of brass strip, and that a vacuum of the order of 1 mm. of mercury was not difficult. In preliminary experiments the question of the saturation of the annealing atmosphere with zinc vapour arose and the control necessary was found difficult; over-saturating the atmosphere caused zinc deposition on the brass, and zinc evaporation when it is under-saturated. He endorsed Dr. Quarrell's remarks with regard to lubricants and supported his plea that metallurgists and oil technologists should get together on this problem.

On the question of selective oxidation, it is of interest to mention that the G.E.C. are engaged at the present

time in installing equipment abroad for the bright-annealing of brass tubes, and have recommended that the brass used in this particular case should contain sufficient aluminium to give a protective film of alumina under selective oxidation conditions. That work has been carried out at Wembley with very encouraging results. The alumina film certainly inhibits zinc volatilisation. There appears to be very great promise in the selection of material of that kind.

In reply to Mr. Chadwick, Mr. Jenkins said burnt ammonia had been used. The main difficulty was to obtain burnt ammonia with a sufficiently low dew-point to give satisfactory stain-free annealing. Much has been said in the literature on the advantages of the dehydration of controlled atmospheres, but he was not sure that such atmospheres are as good as they are claimed to be, and in the case of materials such as brass and stainless steel one hesitates to use an atmosphere which has to be dried when there is an atmosphere available such as cracked ammonia, having probably a far lower dew-point than could be obtained by ordinary dehydrating methods.

Mr. Jenkins could offer very little comment on the points raised by Mr. Lees, other than that he did not think the CO_2 evolved during the de-gassing is associated with carbon in solution in the alloy. The surface gas comes off far too rapidly for one to assume that that can be so.

Replying to the remarks by Dr. Pfeil, he said that interesting experiments had been carried out on the continuous flash annealing of brass wire, but at the moment, the indications are that the time necessary for full annealing is greater than that required for zinc loss and etching; in other words, one cannot hope, with a normal annealing process, to bright flash anneal without having some appreciable zinc loss.

Referring to the comments of Mr. Baker, he said nascent hydrogen, if it does reduce zinc oxide, will only reduce sufficient to set up the equilibrium concentration of water vapour, so that the water vapour will not lead to re-oxidation. The degree of reduction will not proceed to the extent that water vapour will be formed in sufficient quantity to re-oxidise.

The de-gassing of cast brass was not included in the investigation and Mr. Jenkins was not sure that de-gassing at an earlier stage would be an advantage. If the view is accepted that the bulk of the gas evolved by the strip is introduced by impurities rolled into the surface, de-gassing at an earlier stage would probably not materially affect the ultimate surface gas content.

Referring to Mr. Jones' question whether vacuum annealing is really necessary, Mr. Jenkins thought the paper indicates that it is; it is found necessary in order to remove the gases evolved by the brass which lead to oxidation of the surface. He did not understand why Mr. Jones should consider that vacuum annealing presents practical difficulties; it does not in fact do so. If you have a suitably-designed annealing container which can be sufficiently sealed, all that you require is an oil pump, a two-way tap connected to the vacuum pump in one line and to a cracked ammonia or other atmosphere generator in the other.

On the question of the oxidation of brass in a nitrogen atmosphere "probably" being due to impurities in the nitrogen, Mr. Jenkins said he deliberately said "probably," because the work reported in the paper prior to that statement had indicated that gases in the brass contributed to oxide formation, and he was not sure whether, in the nitrogen experiment, the oxidising gases arose from the original nitrogen atmosphere or from the gases evolved from the brass itself.

THE CENTRIFUGAL CASTING OF COPPER ALLOY WHEELS IN SAND MOULDS.

By O. R. J. LEE, Ph.D., M.Sc., and
L. NORTHCOTT, D.Sc., Ph.D.

THE work described in this paper is a continuation of a previous investigation by the Authors* which dealt with light alloys. The objects of the research were:—

1. To provide information on the properties likely to be obtained in wheels of conventional design when centrifugally cast in sand moulds.
2. To provide general information on the influence of casting speeds and conditions.
3. To provide information on segregation and structure of centrifugal sand castings of interest to present users and manufacturers of centrifugal castings.

The technique employed was similar to that described in the previous investigation* on light alloys. The general scheme of investigation for each alloy was to prepare a complete series of castings with $\frac{5}{8}$ in. thick arms; further castings in other variations of the pattern were then made to establish the possible difference in behaviour due to design. Owing to the greater density of copper alloys, the speeds of rotation were lower than for aluminium alloys. The present work standardised on centrifugal pressures of 5, 15, 30 and 50 lbs./in.² and the corresponding speeds used were 225, 380, 560 and 710 r.p.m. for gun-metals and phosphor-bronzes, and 250, 420, 590 and 760 r.p.m. for the less dense aluminium bronze and high-tensile brass.

In the investigation 10 in. diameter wheel castings of five copper-base alloys made in static sand moulds were compared with sand castings prepared in a vertical-axis centrifugal casting machine in which the casting conditions were varied, with regard to rotational speed and casting temperature.

Two main types of alloy were investigated. The type with a narrow freezing range—aluminium bronze and high-tensile brass—is not so suitable for centrifugal casting in sand moulds as the type with a wide freezing range—gun-metals and phosphor-bronze.

As a result of the work done, the authors conclude that, in the aluminium bronze and high-tensile brass types of alloy, a high speed of rotation during casting should be employed, and no metallurgical defects due to segregation or separation of constituents are to be expected. Improvements in mechanical properties of the castings up to the values obtained from static cast test-bars may be expected, but this will not normally represent much improvement over a similar static casting, except possibly at one or two special positions in the casting.

In the tin bronze alloys, centrifugal castings have considerably improved properties over static castings because the latter invariably contain dispersed porosity. This porosity may be due to shrinkage or gas, or both. The greatest improvement in properties was obtained with the phosphor-bronze because the metal/mould reaction produces gas-porosity and results in static castings having a low density. Centrifugal pressure increases the density markedly and more rapidly than is explainable by a simple compression effect. There is thus no reason why the properties of centrifugal castings should not exceed those of a normal static test-bar.

* L. Northcott and O. R. J. Lee. *Jour. Inst. Metals*, 1945, 71, 93.

Because of the degassing procedure employed, the gun-metals should not have contained any gas porosity and there was therefore, less room for improving the soundness by centrifugal casting. For gun-metal not degassed, the superiority of centrifugal castings would be greater than in the present tests. Owing to the fact that static gun-metal test-bars contain some dispersed porosity, there is no *a priori* reason why centrifugal castings should not have better properties than static-test-bars. Although centrifugal castings are denser the higher the speed of rotation, tensile properties do not improve continuously with speed of rotation. The distribution of eutectoid in the microstructure appears to be adversely affected by centrifugal casting and the best mechanical properties are obtained at moderate speeds of rotation. Annealing of centrifugal tin bronze castings to dissolve the eutectoid results in greater improvement in mechanical properties than in static castings, and the improvement is greatest at the highest speeds of rotation. Lead gun-metals suffer only slight segregation of lead in centrifugal casting, but annealing has less benefit in these alloys.

Discussion

Mr. A. J. MURPHY in his comments confessed to feeling puzzled to understand why the centrifugal casting of wheels should have been thought to merit such a profound and detailed inquiry. The instances of plain wheels centrifugally cast in sand moulds without any chill must be very few. An all-sand mould might be used for a simple casting, such as a wheel, cast centrifugally if a chill mould of the right size was not available. Even in that case it would generally be possible, certainly in industrial practice, to provide an iron ring to provide a chill surface at the periphery of the wheel. In that connection, it would be interesting to see a comparison between wheels cast centrifugally in all-sand moulds, those cast with a chill ring, and those cast in all-metal moulds.

Sand moulds for centrifugal castings are more important in cases where the shape of the article is too complicated to be produced from an all-metal mould, and, technically, the question of the strength of the sand mould is of great interest. He asked whether the authors had any indication of mould damage in their experiments. This damage could be caused by thermal shock on entry of the hot metal, by mechanical shock or abrasion by the molten metal striking the mould, and finally at high speeds there is the danger of the mould bursting spontaneously under centrifugal pressure. He suggested that inquiry along those lines might give information of even greater interest to the present users and manufacturers of centrifugal castings.

The consideration of the effect of the density differential between the different constituents was most interesting, but it must be very difficult to assess the influence of surface tension effects on the movement of a liquid metal along capillary channels. In static castings controversies have raged, and still rage, regarding the explanation of the movement of liquid metal in those circumstances; and the matter is in any way simplified when the mould is rotating. In this connection, he asked whether the authors had made any observation of tin sweat on the outside of the rim in these centrifugally sand-cast wheels.

In his concluding comments he directed particular attention to the authors' views on annealing. The three classes of tin bronze, and certainly the phosphor bronze, are used very generally in the as-cast state because of their frictional properties and it should not be omitted from a reference to the annealing of those materials, that their

frictional properties are very seriously damaged by annealing as ordinarily understood. The authors ought to include a warning against these dangers when they are calling attention to the improvement in strength which can be obtained by annealing.

Mr. W. A. BAKER commented on several points and referred to a curve relating the centrifugal pressure of the phosphor-bronze casting to the percentage of voids in the casting, where it is shown that voids in the static casting with no centrifugal pressure are very rapidly reduced by quite small increases in centrifugal pressure. The effect is to dismiss the matter too briefly by saying that it is simply reduction of the volume of the voids by the application of centrifugal pressure. Mr. Baker said that there were two other factors: one is that, in this case, the alloy, as the authors say, is actually absorbing hydrogen from the sand mould during solidification, and there is a good deal of doubt even now as to the progress of that absorption; the other factor which may be involved is that the application of centrifugal pressure, and particularly of a centrifugal pressure gradient, through a sample of metal rotating about an axis, tends to have a de-gassing effect.

He thought the illustration given of the effect of centrifugal pressure on the tensile properties of the castings did not give quite a fair picture, because the values plotted for the castings with no centrifugal pressure were values for static castings made without feeder heads, that is, identical with centrifugal castings, which is not quite a fair comparison. But his main point was a rather sweeping statement by the authors that centrifugal casting virtually eliminated the porosity from tin-bronzes. Their figures show that the castings still contain 0.5 to 1% of voids, which is not by any means a negligible quantity.

Reply by Dr. O. R. J. Lee

In reply to Mr. Murphy, Dr. Lee said the wheel was used because patterns and equipment were available from a previous investigation and it was thought that wheels would be a typical type of casting to investigate the effect of centrifugal casting. With regard to mould damage, he said there was no abrasion effect of the molten metal as it gets into the rim of the casting, because as it is being flung out along the arms of the rotating mould the metal automatically takes up the same speed as the mould, and is therefore, injected from the ends of the arms into the rim in a similar manner to a normal static casting. In the early stages, we had cases of mould bursting, but the use of steel retaining plates prevented any break-out of the sand. Tin sweat on the outer surfaces of the casting was never observed.

With regard to the properties of castings after annealing, Dr. Lee said there is a warning in the paper that annealing will have a bad effect on the proof-stress of these alloys and the frictional properties will certainly be adversely affected; but they had in mind, when mentioning the high strength values obtained after annealing, a usage which was purely for strength properties and not for frictional properties, which it is agreed would be badly affected by annealing.

The figure referred to by Mr. Baker shows the effect of centrifugal force on the density of phosphor-bronze castings... that in the phosphor-bronze castings centrifugal pressure closed up the voids much more rapidly than can be explained on a simple compressibility basis. The point about gas bubbles has been raised previously and Dr. Lee thought after that discussion that possibly the centrifugal pressure acted by preventing the formation of

bubble nuclei in the first instance. He agreed that further work into that effect might lead to very interesting results. The authors were asked to complete their reply in writing and the oral discussion was concluded.

THE FRICTIONAL PROPERTIES OF SOME LUBRICATED BEARING METALS

By P. G. FORRESTER, M.Sc.

THE aim of the investigation described in this paper was to compare the frictional properties of four commonly-used bearing alloys, given in Table I, as regards boundary friction and fluid film-forming capacity, using crankshaft steel as the other member of the frictional pair and a standard crankcase lubricant. As in a previous investigation,* the technique has been adopted of comparing the friction obtained with excess of lubricant with that obtained with a substantially unimolecular film. This comparison, together with observations on the form of the friction/velocity characteristic, gives an indication of the extent of fluid film lubrication under a given set of conditions. The effect of surface finish of steel, temperature, and running-in on the frictional properties of the alloys has been considered.

TABLE I.

Alloy	Composition	μD
Tin-base	7% antimony, 3-25% copper, remainder tin	26
Lead-base	13% antimony, 0-25% copper, 12% tin, remainder lead	31
Copper-lead	30% lead, remainder copper	38
Cadmium-nickel	1-4% nickel, remainder cadmium	31

The results show that there are no important differences between the four alloys as regards boundary friction, as represented by the friction at very low velocities; cadmium-nickel alloy shows significantly lower boundary friction than the others with the standard surface finish, but this difference is not observed with other finishes. It may therefore, be safely concluded that differences in the relative performances of the alloys cannot be attributed to differences in boundary frictional properties.

Considerable differences do exist, however, between the four bearing alloys in respect of one important property—their capacity for aiding or maintaining fluid lubrication. This property will determine the conditions under which boundary friction first occurs in a given design of bearing. The transition from fluid to mixed friction corresponds, approximately, to the minimum observed in the $\mu : \frac{ZN}{P}$ curve. It has been known for

some time that the position of this minimum depends on the bearing material, and McKee and McKee† have shown that tin- and lead-base Babbitts show a lower value of ZN/P at the point of minimum friction than copper-lead alloys. This corresponds to the greater capacity of the tin- and lead-base alloys for fluid film formation, shown by the curves presented here. A bearing must always be designed so that it normally operates within the region of full fluid lubrication; it is clear from these results that lower values of ZN/P are permissible with the Babbitts than with copper-lead alloys, while satisfying this condition. For a fully quantitative comparison between the different materials,

it would be necessary to carry experiments up to the velocity at which fluid lubrication is complete, but this is not possible with the present apparatus.

Almost all bearings must operate, however, for limited periods within the region of mixed friction. This region is passed through, for example, when stopping or starting. Departures from alignment, or the presence of grit particles, may also cause some degree of boundary friction. In these circumstances the fluid film-forming capacity of the material will determine the area subject to boundary friction and, hence, influence the amount of surface damage to be expected, the frictional losses incurred, and the amount of heat evolved. Here again a full knowledge of the friction/velocity characteristic is required for accurate quantitative comparisons. The evidence obtained in the present experiments does give however, some idea of the magnitude of the differences to be expected.

For example, consider the behaviour of a bearing when starting from rest. Some boundary friction and consequent surface damage are inevitable. It is a reasonable assumption that the amount of surface damage is associated with the work done against boundary friction. Since fluid friction is always very small, almost the whole of the observed friction is due to boundary friction; a close estimate of the work done in starting may thus be calculated from the observed friction/velocity relationship.

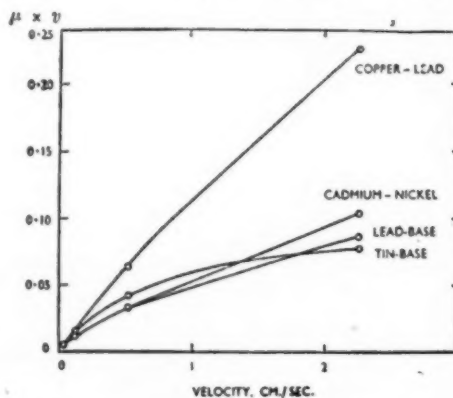
When a bearing moves from rest the work done is proportional to $\int_0^{v_1} \mu ds$, where v_1 is the velocity attained.

But $v^2 = 2as$, where a is acceleration, assumed constant, so that

$$2v = 2a \frac{ds}{dv}, ds = \frac{1}{a} v dv$$

$$\text{So work} = \frac{1}{a} \int_0^{v_1} \mu v dv$$

In the accompanying illustration, reproduced from the paper, μv is plotted against v for the four alloys on run-in grade "O" emery surfaces at room temperature.



Curves showing μv plotted against v .

The work done in starting is proportional to the area under this curve. This area is much greater for the copper-lead alloys than for the other three alloys, and the difference is rapidly increasing with increasing velocity.

* P. G. Forrester, *Proc. Roy. Soc.*, 1946 (A), 187, 439.
† S. A. McKee and T. R. McKee, *Trans. Amer. Soc. Mech. Eng.*, 1937, 59, 721.

The areas for tin- and lead-base Babbitts are almost identical, while cadmium-nickel alloy gives a rather greater area.

Similar arguments apply when boundary friction results from any other disturbance of normal conditions.

Discussion

DR. BRUCE CHALMERS said the method of experiment adopted in the work described in this paper was worth examining. It made no attempt to imitate the general geometrical conditions which prevail in a bearing when it is moving. Many tests in the past have attempted simply to simulate the condition in the bearing, and have thereby, perhaps, failed to produce the fundamental information on which a proper understanding of the action of bearing metals must be based. In the author's method of experiment, on the other hand, a rotating disc is used on which are pressed three spherical pieces of bearing metal, the disc consisting of metal which is regarded as equivalent to the journal on which the bearing runs. A normal load is applied between the three projections and the bearing surface, and the frictional force is measured directly by means of the friction-balancing load. This allows the influence of speed, the influence of temperature, the influence of the amount of lubrication present, and the influence of the amount of previous running to be assessed independently; and it is the ability to assess these four things independently which makes it possible for this method of experiment to give results of fundamental value.

It is shown that it is not so much the actual frictional property of the lubricated metal which matters, but the ability of the metal to avoid running into the region where that frictional property seems to matter most.

The author suggests that the differing behaviour of the four different bearing metals in this respect is tied up with a property which he calls "micro-conformability"—the ability of the two surfaces to conform very closely to each other while running is in progress. This is obviously a dynamic property; under static conditions presumably the hardness of the softer material would determine how much conformability there was and how closely two surfaces did actually coincide geometrically. On the other hand, when one surface moves relatively to the other, the softer material must be continuously changing its shape, and would involve a tremendous amount of working of the material if it goes on all the time that the bearing is running. He asked, is it possible that it is not the continuous local deformation of the softer material which is the cause of this difference, but the amount by which the softer material is able to grind the surface of the harder material, perhaps by virtue of the hard constituents present in the soft bearing metal?

He thought that little could be done about the co-efficient of friction, because there was not a great variation between the possible materials that were used; the selection of a suitable bearing metal does seem to depend very much more on avoiding damage to the bearing, and that damage is shown to be associated very closely with the distinction between the persistence of fluid film and the appearance of boundary lubrication.

MR. J. CARTLAND said that the particular point with which the author dealt, the relationship between boundary lubrication and fluid lubrication, is of vital interest. In considering the author's results it should be kept in mind that his set-up is entirely different from that of a bearing in a journal. He asked whether the author could help to visualise the situation between boundary and fluid lubrication

and the effect of surface finish by giving some general idea of the relative sizes. By "relative sizes" he meant the size of the unimolecular film prepared by the method which the author described and the size of a full fluid film lubrication thickness, compared with the excrescences on the three grades of steel of which he has given some indication of size.

In considering the results illustrated in the paper, he thought it a remarkable feature that the friction with the rubbed film was so little greater than the friction with excess of lubricant and significant that the tin-base bearing metal shows a distinct advantage over the lead-base bearing metal on the rougher-finished steel.

In his concluding comments, Mr. Cartland said the author's study of these frictional properties was most interesting, but when considering bearing practice he thought it should be borne in mind that there were other properties of bearing metals of at least equal importance. For instance, the property of bonding to the shell, which is outside the scope of this paper. "No bearing is any good unless the bearing metal is completely bonded to the shell, and the bonding properties vary widely with the composition. Then there are all the usual mechanical properties, and there is also the property of absorbing steel chips, grit and other material into the bearing in such a way that it does not score the shaft in the bearing in operation."

MR. H. G. WARRINGTON said we are all searching for some more fundamental theory of bearing materials. What we lack in regard to bearings is a fundamental theory on which to produce new and better bearing alloys. It is, therefore, with the greatest interest that we look forward to such a paper as this, hoping to get perhaps one step nearer this objective. The development of the bearing alloys has mostly been due to *ad hoc* work from bearing practice and not to a real, fundamental theory. Theories have been put forward of duplex structures and at the same time many bearings have been made from pure metals, and comparisons can be made. Many scientific theories and hypotheses have been developed from analogies, and other materials can be taken for bearings, outside those which have been used in the work described, in order to see what effect they would have on his results.

There is, for example, the silver bearing. The silver bearing seems to support the author's hypothesis of conformability or softness as a fundamental property of bearings. This is a bearing metal which is not particularly suited to all bearing conditions. It does not support an oil film very well; by plating its surface with lead and the lead with indium, a type of bearing is formed which works reasonably well—under most conditions almost as well as a tin bearing, and under some conditions, under which a tin bearing will not stand up, it seems to work better.

This looks like a very strong circumstantial argument in favour of a fundamental theory of conformability. On the other hand, however, we have some new materials in the bearing field which seem to prove the very opposite. There have been many attempts to make aluminium bearings in this country, some time ago Hall and Bradbury developed the "Rolls-Royce" type of alloys, which were used in car engines and to a certain extent in aero engines, with an aluminium base. These alloys, however, contained a fair amount of tin, about 6%.

Mr. Warrington wondered what function the tin performed in such an aluminium alloy bearing material. It could hardly be said that there is sufficient tin present to produce any effect on conformability, and the equilibrium diagram suggests that it is in solid solution. Is it that tin has some

other feature which will produce a surface effect of benefit in bearing materials, even when the tin is present to the small extent of 6%, with some 90% of a material which is normally considered to be quite foreign to any of the properties associated with bearing alloys? He was of opinion that a little thought on these lines might lead to some further interesting development on the fundamental theory of what is a bearing material.

Dr. D. TABOR's contribution to the discussion was read by MAJOR ASKEW referring to one of the main points emphasised by the author, that of "conformability," which is largely determined by the hardness of the bearing alloy, and said that, in practice, bearings do not run at the very low surface speeds used in these experiments and at higher speeds of sliding the surface temperatures of the shaft and the bearing may be relatively high. Consequently, the important factor in determining the conformability will probably be the hardness of the bearing alloy at the running temperatures actually operating, rather than the hardness values at room temperature. Thus, it would be interesting to know whether any attempt had been made to correlate the hardness at elevated temperatures with McKee's bearing experiments.

As is well known from the theory of hydrodynamic lubrication, he continued, the occurrence of fluid lubrication depends on the ZN/P characteristics of the system. If the viscosity Z of the film is high, fluid lubrication may set in at very low sliding speeds. For this reason, lubricants containing small quantities of fatty acids may facilitate the occurrence of hydrodynamic lubrication. This is because the fatty acid, in general, reacts with the surface to form a thin film of metallic soap which is enormously more viscous than the bulk of the lubricant itself. In experiments with cadmium surfaces, for example, Gregory found that the soap film is formed even if the fatty acid is present in a concentration less than 0.001%. It would be interesting to know whether the mineral oil used in these experiments was completely free of fatty acid.

He criticised the assumption that the amount of surface damage is associated with the work done against boundary friction. There is no real evidence that this assumption is valid. In general, there appears to be no direct relation between wear and friction. Most of the frictional work appears as heat; the work done in abrading the material at the surfaces is usually a very small fraction of the total frictional work. Consequently, the wear may vary over extremely wide limits without appreciably affecting the friction.

On the properties of bearing alloys, Dr. Tabor stated that, in practice, bearing alloys fall into three main groups. The first class is the white metal type of alloy, consisting of hard particles embedded in a softer matrix. Recent work shows that the hard particles play no significant part in the frictional properties of the alloy, although they may have a desirable effect in stiffening the alloy and in producing minute crevices where the oil may be secreted. It would seem that the retention of the hard particles in the matrix is largely an accidental result of the historical development of this type of bearing alloy. The second class consists of a hard matrix through which a softer metal is distributed. Experiments show that during sliding the soft metal is expressed and smeared over the matrix, where it functions as a thin metallic lubricant film. These alloys are relatively hard and function under more extreme conditions than white metal alloys. The third class is a single metal or a single phase alloy. Here the frictional process is essentially the same as that of the

matrix material of an ordinary white-metal alloy. It is evident, therefore, that there is no single mechanism that explains the action of all types of bearing alloys.

There is, however, one property that is common to a very wide range of bearing alloys that appears to be of great importance; they all contain a constituent of relatively low melting-point. It is clear that this characteristic will prevent excessive seizure, since the high local temperatures developed under severe conditions of running will readily cause a local softening or melting of the low-melting constituent at the regions of momentary contact. The molten or plastic material will then be carried round to a cooler portion of the bearing. It follows that, apart from suitable mechanical, frictional and wear-resisting properties, a very desirable property of a wide class of bearing alloys is that one of its constituents should possess a relatively low melting-point.

Mr. D. CLAYTON expressed support for the author's statement that bearings in general should be designed for fluid film lubrication, that in the vast majority of cases they do in fact, run under fluid film conditions. Even under ideal conditions there are two cases to consider. There is one in which the load on the bearing increases with the speed, and then the starting and stopping is no problem; the other case is dead-weight loading, in which the starting and stopping are important. Under ideal conditions therefore, where, when running, there is a fluid film, boundary friction does come in as an important factor.

Metallurgists, however, are interested in bearing metals not because of their fluid film properties but because of their boundary properties, in addition to such general factors as bonding, single or dual phases, and so on. The point is that bearings do wear, although in many cases they run under fluid film conditions; there are others that wear, and some go to seizure. It is true of boundary conditions that they react in that respect, and so it is important to consider boundary conditions for bearing metals.

There is surprisingly little information on the subject, as previous speakers have said, and, as the author points out, much of it has been very empirical. No analysis has been carried out to find out just what is the boundary coefficient. The author started with the idea of finding what the boundary coefficients were, and he has, as a result of what can be regarded as a very effective piece of work, been able to give an explanation (which is always important) of what has been determined empirically; but he has had to word his report so as not to claim boundary coefficients of friction.

Mr. A. CRAIG MACDONALD thought there was a danger of placing undue importance on the results of friction tests of this kind. Bearings have to work, and the number of factors entering into their satisfactory operation is, of course, very much greater than the number dealt with in the paper. It has been mentioned that this work particularly applied to the bearings of internal combustion engines. In the big-end bearings of modern high-duty engines, bearing metal has to withstand the most severe duty to which it is subjected anywhere, and he felt that the manner in which the engine responded was the correct interpretation. Work of the kind described in the paper is very valuable in showing the effects of certain fundamental differences, but in the end what the engine says is right.

He mentioned one or two specific points—for example, the reference to Dr. Tabor's work, and the statement that he showed that the presence of compounds had no very

considerable effect on the frictional behaviour of the lead- and tin-base materials. The engine says that that is not so. In the internal combustion engine manufactured by the company with which he is associated, tin-base bearing metal has to do a tougher job than anywhere else in the world. These are the only high-duty compression-ignition engines which are still running with tin-base white metal linings in the big-end bearings, with one exception, and in that exception the engine is running at a slower speed and the bearings are rather greater in area. He was drawing attention, therefore, to the white metal lined bearing which had, he thought, the toughest of jobs. In several hundred thousand miles of engine life, it is known that the presence of compounds, while they may have no definite effect on the frictional behaviour, involve such an effect that the life of the bearing is very considerably affected.

To do satisfactorily the job he had described, it had been found that a cuboid structure must be used. There is a very marked difference in the life of the bearing if the tin-antimony cuboids are not properly formed. It may be a difference of 100,000 miles as against 250,000. He pointed out that either of these periods of service represented an extraordinary job of work, and as far as the bearings themselves were concerned, even the shorter of these lives was an amazing tribute to metallurgical development.

In order to get the fatigue life of the bearings satisfactory, taking into account all the other problems, linings had to be 0.004 in. in thickness. Lesser thicknesses were extremely difficult to produce commercially, and any greater thickness reduced the life. The structure has to be so controlled that the cuboids are of a certain size. It is quite possible, in cooling white metals of this kind, to have cuboids 0.002 to 0.006 in. in height, and, if the lining is only 0.004 in. thick, in the final machining operation the tendency is to dig out the cuboids and leave the tin-copper matrix. When the cuboids are controlled to be 0.002 to 0.001 in. broad, and the lining is 0.004 in. thick, the life of these bearings is remarkable.

Mr. MACDONALD asked how the copper-base alloys, to which the author referred were manufactured. If they were manufactured by the method originally used in this country and in America, where the lead is distributed as lakes in the copper, there is a very limited feed of lead to the surface to keep the friction down. If they are made as is now done in America, by distribution of strip in such fashion that the copper stands up as trees and the lead is distributed amongst them, then, from the point of view of this paper, the bearing will have the properties suggested. It is equally true that if they are made as interlocked sponges by the sintered metal process, using copper and lead powder, the strength of the matrix is greater than in the American bearing, and the feed of lead to the surface is much more satisfactory than in the original British bearing.

Mr. H. H. A. GREER said there seemed to be no standard whatever for white bearing metals. For the mercantile marine the question of price predominated. Vast quantities of white bearing metals are so different in composition that this paper should be studied by consulting engineers to find out not what is the cheapest but what is the best quality to use.

Reply by Mr. Forrester

Dr. Chalmers suggests that one explanation of the property to which I refer as micro-conformability is that the soft material may grind the crankshaft material, the steel, and therefore change its surface characteristics. I do not think that that is actually the case, because if we run for a little while with white metal on a given steel

plate, and then substitute a new plate for the old one, the results are very little affected. I think that it is a genuine case of continuous conformation of the soft slider to the hills and valleys of the plate. Mr. Cartland further emphasised the importance of boundary lubrication, or tests of boundary lubrication, and I heartily agree with him on that. The loading on the specimen is not infinity, as he realises, but the flow pressure of the material. When the slider is first put on the plate the pressure, of course, is instantaneously infinity, and then the material flows until the area of contact is established which is sufficient to support the slider.

I agree with Mr. Cartland that I should have given some idea of the actual sizes in mentioning the films involved. With regard to the sensitivity of the apparatus and the apparent discrepancies between results, I hold by the statement that the sensitivity of the apparatus is about 0.0025, but that is not the reproducibility, because the difficulty lies in reproducing surfaces sufficiently accurately.

Mr. Warrington suggests that electro-polished finishes would be of considerable interest, and I quite agree that that would be well worth trying. We have tried etched surfaces, which would remove the flowed layer, and they are utterly different in properties from normal machined finishes, but we have not investigated that a great deal. His remarks with regard to aluminium-tin bearings and silver-lead bearings were to a large extent answered, I think, by the later contribution of Dr. Tabor. I think that both of those bearings depend on the formation of a thin lubricating film of metal on the surface of the harder material. The aluminium-tin bearings are, I believe, duplex; the tin is distributed in pools in the aluminium or aluminium alloy and can flow to the surface and form a very thin film there.

We have not so far, been able to obtain any evidence of the effect of fatty acids on the lubricants in the formation of fluid film, but the experiments to that end have only been very cursory so far, and we may yet find such an effect. Dr. Tabor made the point that many bearing alloys have one property in common, a low melting point constituent; and, as his work and that of Dr. Bowden shows, this is a very valuable property of the bearing metal.

Mr. Clayton points out that bearings normally run under fluid film conditions. He would probably vary that to say 99%; there is evidence that occasional touches do occur in running almost all bearings. It is, of course, at the times when that fluid friction does not operate that damage is done to the surface, and it is that damage rather than the power loss which is important. I should like to be able to quote definite boundary values for these oils, but we cannot do it yet, for the reasons explained in the paper. We can do it for harder alloys, but with this evidence of fluid film formation under conditions where every effort is made to suppress it we cannot give an accurate value of boundary friction, but only an estimate.

In reply to Mr. Craig Macdonald, I would say that certainly undue importance should not be given from a practical point of view to friction tests of this type. This is fundamental work which may help in interpreting bearing tests, but the real answer, as he says, is in the engine. The way in which we do hope that this work will be useful is that when it is necessary to change the old bearing alloys or develop new ones we hope that every effort will be made to see that we do not lose the good properties in developing new ones—that we do not, for example, lose the merit of low-temperature constituents and the merit of low-hardness constituents solely in order to put up the

fatigue strength, because if we do we shall run into other difficulties.

Mr. Craig Macdonald refers to the use of very thin linings. It must, I think, be quite an engineering achievement to get a standard 0.004 in. lining. Such a lining will not only have high fatigue strength but also to some extent, I think, operate in the same way as the thin lead film of a copper-lead bearing. There will probably be even lower friction with his thin Babbitt than with a thicker one.

JOINT DISCUSSION OF PAPERS ON THE CORROSION OF MAGNESIUM ALLOYS

A very informative discussion took place on three papers dealing with the science and technology of magnesium corrosion. The first paper in the series, that by Mr. E. R. W. Jones, B.A., and Mrs. M. K. Petch, B.A., describes an investigation on the variation in corrosion properties over two magnesium alloy sheets to specifications D.T.D. 118 and D.T.D. 120A (AZM). A fairly random variation, probably due to the method of test, was observed on material to specification D.T.D. 120A. A large systematic variation occurred, however, in the material to specification D.T.D. 118 and it was found to be associated with a similar variation in the iron content of the material. An attempt to allow for the variation by interpolation failed to give useful results.

The second paper, that by Dr. F. A. Fox and Mr. J. K. Davies, B.Met., describes an investigation on the corrosion of some magnesium-base alloys, of high and normal purity, in contact with other metals. The magnesium-base alloys, which mainly contained 5% aluminium of normal and high purity, were immersed in 3% sodium chloride solution saturated with magnesium-hydroxide, while in electrical contact with other metals. The results show that while the galvanic corrosion of many magnesium-base alloys is anodically controlled, the magnesium-aluminium alloys behave differently. It is suggested that the surface anodic film is unstable and non-adherent, and that the corrosion is controlled by cathodic reactions. Despite the advantage of a lower corroding potential, the alloys of normal purity corroded at a higher rate under conditions of galvanic attack than those of higher purity alloy, owing, it is suggested, to the greater number of local galvanic cells in the material of normal purity. The work shows that, in general, the cast magnesium alloy containing 5% aluminium behaves anodically to other metals when immersed in the corroding solution, exceptions being cast aluminium of high purity and some Elektron alloys.

The third paper, that by Mr. C. J. Bushrod, M.Sc., deals with the quantitative implications of Hanawalt's theory of corrosion of magnesium-base alloys and attempts to apply mathematical treatment to so difficult a subject as corrosion problems. The theory, postulated by Hanawalt, Nelson, and Peloubet, to account for the influence of traces of iron and other impurities on the corrosion of magnesium-base alloys, is developed on a quantitative basis. The resulting equation is shown to agree with experimental results previously obtained, using two alloys of differing iron content. It is suggested that the equation should be fitted to results obtained from alloys in which the impurities were subject to closer control but, in addition, *a priori* reasons are given for supposing that the basis theory is incorrect.

There was very considerable discussion on these papers by Dr. H. Sutton, Dr. F. A. Fox, Dr. Bruce Chalmers, Dr. F. A. Champion, Mr. C. F. Bushrod, Mr. J. K. Davies, Mrs. Marion Petch and Mr. E. R. W. Jones, and, as there was insufficient time for the authors to reply, they were asked to do so in writing. Lack of space prevents us presenting a report of the discussion here, even in a substantially condensed form. Complete reports of the various discussions will be published in subsequent issues of the Journal of this Institute.

Course in Gas Turbine Technology

REPRESENTATIVES of nine countries are attending a course in gas turbine technology, which is being held at the National Gas Turbine Establishment School at Lutterworth. The course, which commenced on October 5th, and will last for three weeks, has been organised by Power Jets (Research and Development) Limited, of 8, Hamilton Place, W.1, following the great success of an earlier course held in February of this year. A further course will commence on Nov. 10.

Sixteen graduate engineers, including professors and doctors, from Argentina, Belgium, Czechoslovakia, Denmark, Holland, Egypt, Italy, Switzerland and the United States are here to study British gas turbine technology, and they will see how the technical knowledge that gave Britain world supremacy in the gas turbine aero-engine is helping us to establish a lead in the use of the gas turbine in marine, locomotive and industrial installations. In addition to basic academic theory, a number of lectures is being given by specialists in particular aspects of the work, and the whole range of gas turbine applications will be covered.

Tin and Its Uses

THE current issue of the above publication contains a number of interesting and informative articles. Of particular interest is an editorial which directs attention to the enormous profits to be obtained from applied industrial research in which bearing metals are cited. One of the articles is concerned with tin as an undercoat for painted steel and its title asks the question "Must Iron Rust?" A comparison is given of identical steel panels painted directly, omitting a tin undercoat and a further series after different rust-prevention treatments: various paint compositions are used and tests with various steels have been carried out over four years. Reproductions of the natural colour photographs of samples show marked differences in the condition of the tinned and the untinned steels and illustrate the protective value of tin as an undercoat for painted steel.

Another useful article refers to modifications in the methods of manufacturing chill cast tin bronze arising from recent researches, which have led to appreciable economies in production costs as well as to considerable improvements in the qualities and mechanical properties of the product. It is noteworthy that bronze containing 8 to 14% tin can now be fabricated by hot-working methods, such as forging, stamping or extrusion, or may be cold worked by rolling or drawing. The issue contains several further informative articles a copy of which may be obtained free of charge on application to the Tin Research Institute, Fraser Road, Greenford, Middlesex, or from the Battelle Memorial Institute, 505, King Avenue, Columbus, Ohio, United States of America.

The Heat-Treatment of Steels Without Decarburisation

By R. A. P. Misra, A.F.R.Ae.S.

In the heat-treatment of many steels scaling and decarburisation are encountered to varying degrees and to reduce their effect involves a consideration of controlled atmospheres. In some cases a slightly oxidising atmosphere is used to prevent carburisation, in others the atmosphere may be slightly carburising as a deterrent to scaling. In this article is described a new method of producing and maintaining a suitable atmosphere which is both simple and practical and which is giving excellent results in heat-treatment operations.

THE following requirements must be fulfilled if an atmosphere is to be practically and commercially successful in the general heat-treatment of steels:

1. Lowest possible cost.
2. Simplicity of operation.
3. Neutral reaction with respect to decarburisation of steels at all normal heat-treatment temperatures and with alloy steels of varying carbon contents. This requirement is particularly important in the case of medium and high carbon steels.
4. Minimum oxidation characteristics consistent with (3) above.
5. Freedom from explosion risk and absence of toxic characteristics.
6. Independence of supply services such as gas, compressed air, or special fuels which may not be easily available, e.g., bottled hydrocarbon gases (methane, butane, etc.).

There are other characteristics which are desirable when using an atmosphere protection such as generation at a high temperature and a high degree of turbulence; both these factors shorten the heating-up time and help to reduce the overall heat-treatment cycle in the furnace.

Most practical metallurgists have been faced with the problem of decarburisation when dealing with the heat-treatment of steels in protective atmospheres. In fact it is generally conceded that some degree of decarburisation is unavoidable when bright long-cycle treatments are carried out in controlled atmosphere furnaces. It may be stated quite candidly that the advent of the protective atmosphere was responsible for focusing the attention of heat-treatment technicians on this problem. It is untrue to say that the problem did not exist in the days of the old fuel-fired furnaces, but its presence was often masked by the common practice of grinding or machining the heat-treated surface to obtain a better finish. Advances in the technique of surface hardness testing, e.g., the general introduction of the Vickers hardness testing and like machines, and the more common use of the metallurgical microscope have given a quantitative as well as a qualitative valuation to a fault which once was described merely as a soft skin. In some cases the depth of the decarburised layer can be more than skin deep and samples with 0.025 in. depth are not unknown. There can be little doubt regarding the necessity of eliminating decarburisation as its detrimental effect on the surface hardness and fatigue strength of steels is well known. The presence of a decarburised layer will reduce the fatigue strength

of steel by 50% or more depending upon the extent and nature of this fault. When it is realised that over 90% of mechanical failures are due to fatigue from one source or another, the true significance of eliminating decarburisation will be appreciated. Seizure of hardened bearing surfaces may be traced to the presence of a decarburised layer or local soft areas. Failure of the cutting edges of tools may be due to the same fault and, although in many cases it may be removed by grinding or machining, this is not always possible on account of the shape of the article. Removal of decarburised material inevitably increases the cost of production, but often has to be undertaken in order to produce an article to precision limits. In such cases the minimum grinding allowance which will give a cleaned-up job free from any traces of decarburisation is desirable from the point of view of economy in production. Much of the confusion which has arisen regarding this subject is due to the inherent simplicity of producing controlled furnace atmospheres by controlling the combustion of carbonaceous fuels. Because it is desired to produce work with the minimum amount of scale, what could be more natural than to imagine that this could be achieved together with freedom from decarburisation by reducing the supply of air in the fuel-air mixture and thus produce a reducing atmosphere. Most people believed that as long as the carbonaceous products of combustion were reducing they could not be decarburising. This, unfortunately is not true for it is possible to have a reducing atmosphere which is also decarburising; in fact it is possible to have three distinct combinations namely:—

1. Oxidising and decarburising.
2. Reducing and decarburising.
3. Reducing and carburising.

It is possible, however, to produce commercially an atmosphere giving, on high carbon and similar steels, results which are free from practical decarburisation, together with negligible dimensional changes.

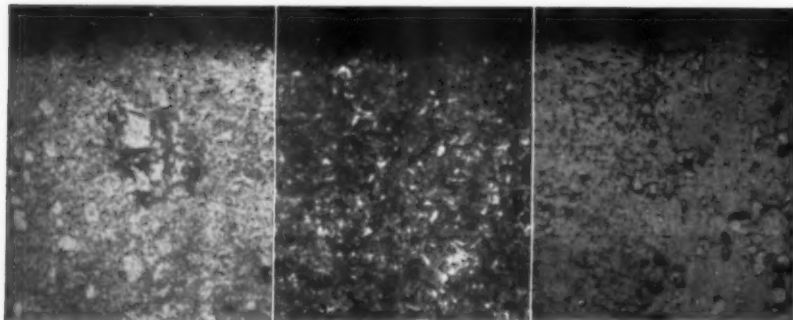
Before proceeding with the description of this development a few notes are necessary as to what is meant by freedom from decarburisation together with no dimensional change.

Many practical metallurgists and engineers agree that a file test when properly applied can provide a very good indication of decarburisation on hardened high carbon steels. This test was used in conjunction with confirmatory Vickers Hardness figures and micrographic examination. The amount of material removed by polishing with fine emery paper was kept down to the minimum necessary to obtain a polished surface suitable for hardness testing and did not in any case exceed

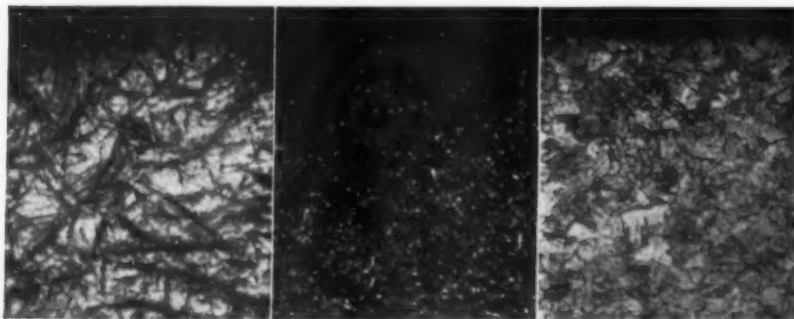
0.0005 in. Hardness tests taken on the Vickers machine employed a load of 20 kgs. with a two-thirds objective. For dimensional checks 0.5 in. diameter test pieces of lengths varying from 0.5 in. to 2 in. were used. The material was plain 1% carbon steel and the rod was centreless ground stock to limits of ± 0.0001 in. The test pieces were measured before and after heat-treatment which comprised heating the specimens at 780°C. for one hour followed by a water quench. After heat-treatment the diameter was not less than the original size. In some cases there was a slight growth amounting to a few ten-thousandths of an inch.

Extensive work was undertaken and practically every type of steel commonly used in the engineering industry was heat-treated in this atmosphere with satisfactory results. The following list gives some of the types of steel tested:—

1. 1% C plain carbon steel.
2. 0.2/0.25% plain carbon mild steel.
3. S. 82. Ni Cr case hardening steel—gas carburised.
4. 2% C 12% Cr die steel.
5. B.S.S. No. 5 Ni Cr Mo, 0.5/0.6% C steel.
6. 1.1% C water-hardening steel.
7. 0.5% C water-hardening steel.
8. S14 plain carbon case hardening steel—gas carburised.
9. Silico-manganese spring steel.
10. Ni Cr Mo, case hardening steel—gas carburised.
11. 1.5% Cr 1% C ball race steel.
12. 10% W die steel.
13. 18/4/1 High speed steel.



12% Cr 2% C heat treated H.S.S. 18/4/1 preheated and 1.1% C tool steel, hardened
 $\times 250$, Etchant—Aqua regia, hardened, $\times 250$, Etchant— $\times 250$ Etchant—2% Nital,
 Aqua regia.



Ni-Cr-Mo oil hardened steel—S.82 carburised refined and Mild steel heat treated $\times 250$, Etchant—
 $\times 250$, Etchant—2% Nital, hardened, $\times 250$, Etchant—2% Nital.

Photomicrographs of some of the samples treated showing no signs of decarburisation.

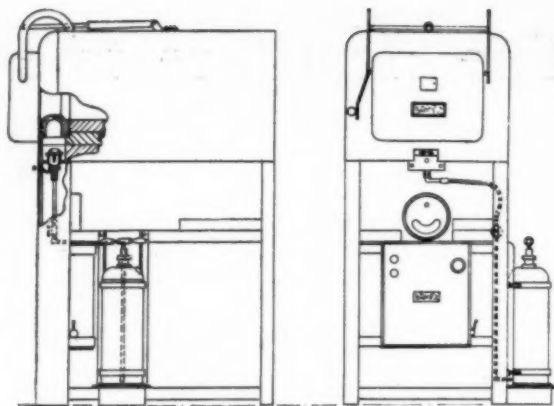


Fig. 1.—Showing atmosphere-producing apparatus fitted to a small high temperature heat treatment furnace.

Brief details of results on a representative number from the above list are given together with reproductions of photomicrographs at the immediate surface of some of them. It will be seen that there are no signs of decarburisation on any specimen and full hardness figures are obtained in every case.

Finish.—No attempt was made to produce a bright finish as it is impossible to produce this with an open furnace without special quenching arrangements. The object was to produce a commercially acceptable finish free from decarburisation, which would be file-hard and

would give the desirable silvery-white finish after shot blasting. This last-mentioned test is a very good indication of freedom from

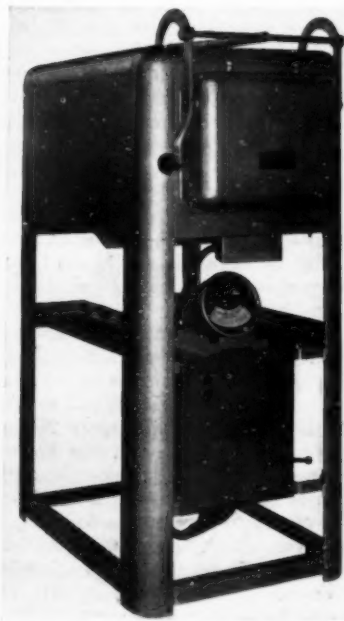


Fig. 2.—Illustrating the type of furnace used for the experiments.

DETAILS OF EXPERIMENTAL RESULTS ON A NUMBER OF STEELS.

Sample No.	Steel specification and previous heat-treatment, if any.	Treatment in Paragen burner atmosphere in horizontal "Workshop" furnace.	After heat-treatment. Finish. V.P.N'S20/2/3*
C.	S.11 mild steel—previously gas carburised to a depth of 0.04 ins.—in the slowly cooled condition.	1. Refined core at 880/900°C., 15 minutes at temperature, then water quenched. 2. Hardened case at 780° C., 20 minutes at temperature then water quenched.	Scale free, 866, 825. Scale free, 883-874
E.	12% Cr 2% C, in normalised condition.	Heated to 960° C., and maintained at that temperature for 1 hour, then oil quenched.	Clean, but black, 701, 701.
G.	H.S.S. 18/4/1 type.	1. Preheated slowly to and maintained 10 minutes at 900 C. 2. Transferred to high temperature furnace at 1250°C., and raised to this temperature over five minutes, then oil quenched.	Clean, black finish, 788, 788.
H.	B.S.S. No. 5. NiCr.Mo. 0.5/0.6 C steel in fully annealed condition.	Heated to 830° C. and maintained at this temperature 1 hour, then oil quenched.	Clean, black finish, 840.
I.	0.29/0.25% C mild steel in normalised condition.	Heated to 925°C., and held at temperature 35 minutes, then water quenched.	Clean, scale free, no carburisation, 180.
F.	1.1% C tool steel in normalised condition.	Heated to 790° C., and held at temperature 1 hour water quenched.	Clean, 818.
29.	1.5% Cr, 1.0% C ball race steel.	Heated to 820° C., and held at temperature 30 minutes, then oil quenched.	Clean, black finish, 848.
20.	8.82 NiCr.C.H. steel previously gas carburised to give 0.06 in. case—very slowly cooled.	1. Refined core at 840° C., 20 minutes at temperature, then oil quenched. 2. Hardened case at 780° C., 20 minutes at temperature, then oil quenched.	Clean, black finish, 726. Clean, black finish, 773.
21.	0.5% C water hardening steel.	Heated to 840°C., held at temperature 1 hour then water quenched.	Clean finish, 780, 780.
28.	2% Ni.Mo. C.H. steel, gas carburised depth of 0.04 in.—slowly cooled.	1. Refined core at 840°C. 20 minutes at temperature, then oil quenched. 2. Hardened case at 780° C., 20 minutes at temperature, then oil quenched.	Clean, black finish, 802. Clean, black finish, 802.
26.	Si. Mn. Spring steel.	Heated to 840° C., held at temperature for 30 minutes, then water quenched.	Clean, 802.

* At immediate surface.

decarburisation of steels in the hardened condition. Decarburised areas shew up as dull against a silvery-white background. This test was applied to a number of 1% C carbon steel test-pieces, with entirely satisfactory results.

Construction of Apparatus

The apparatus employed in the production of this atmosphere is simple, it has been developed by Messrs. Wild-Barfield Electric Furnaces, Ltd., and is called the "Paragen" burner, for it utilizes ordinary paraffin or kerosene as its fuel. Provisional patents and trade marks have been applied for. The atmosphere producing apparatus is of extremely simple construction being illustrated in Figure 1 and consists of a fuel container of 2 gallons capacity for small furnaces, which incorporates a hand pump for producing an air pressure of 10-20 lb./sq. in. a pressure gauge being provided in a position where it is readily visible. A large diameter filler cap is provided with a funnel which is fitted with a fine gauze strainer to prevent entry of water or dirt with the paraffin. The actual filler cap on the container, acts as a relief valve for the container.

The fuel is passed under pressure through a pipe line, which is provided with a needle valve, to the vapourising burner which is fitted under the sill-brick of the furnace. The burner is of the well-known "Primus" silent type in which the fuel is vapourised and the vapour is mixed with the correct amount of air before combustion. Most people are familiar with the method of starting and operating these burners and no further description is necessary here. The products of combustion, which are at a very high temperature, pass through a slot in a specially designed sill brick and into the furnace. After passing round the work in the furnace the atmosphere leaves the furnace through a flue in the back wall of the furnace. It is important to ensure that this flue is kept

open to enable the gases to circulate freely in the chamber.

The fuel is easily obtainable in any part of the world and the consumption is very economical being approximately 24 hours per gallon of paraffin for a single burner installation. Thus it will be seen that the cost of this atmosphere is very low. Other advantages are simplicity of operation: low initial cost of fuel: relative freedom from sulphur compounds. The atmosphere plant is completely self-contained and the composition of the atmosphere cannot be altered by changes in gas or air pressures. Figure 1 shows in diagrammatic form the apparatus applied to a horizontal "Workshop" furnace Model H.W.21. Figure 2 shows a photograph of the furnace, without a Paragen burner. The simplicity of the apparatus will be apparent upon comparing the two figures. Although at the moment this atmosphere is available only on the above furnace, work is proceeding to apply it to those of the range of Wild-Barfield furnaces for which it may be suitable.

Theory.—The industrial application of a suitable protective atmosphere for the heat-treatment of carbon steels, presents more difficulty than almost any other heat-treatment problem. A vast amount of research work has been published on the subject of carburisation and decarburisation; nevertheless, the production and maintenance of an atmosphere which gives entire freedom from decarburisation in commercial furnaces—particularly of the standard batch type—has hitherto been almost impossible. The constant opening of the furnace door for the introduction and removal of work has presented many difficulties, which have not been overcome entirely by the provision of protective screens of atmosphere across the furnace mouth.

It is suggested that the "Paragen" burner, which has given the results indicated in this paper, has a number of features which contribute to successful

heat-treatment of carbon steels with practical freedom from decarburisation, namely :—

(a) *Temperature of generation.*—The atmosphere is generated virtually in the furnace itself, and the hot gases, whilst they are always cooled down to the heat-treatment temperature of the furnace, do not cool down to ambient temperature by virtue of ancillary coolers and the like. Thus, altogether the combustion of the fuel is practically complete, at normal heat-treatment temperatures for carbon steels, the mixed gases are sufficiently high in CO content to suppress the decarburising action of the CO₂ and water vapour.

(b) *Turbulence.*—The "Paragen" burner is designed to give a high degree of turbulence to the products of combustion. This assists in rapid purging of air from the

furnace and ensures a constant supply of fresh atmosphere over the parts being heat-treated. The necessity for an efficient flue will be obvious.

It is more than probable that there are other theoretical factors which are present and account for the results obtained, suffice it to say in conclusion that the "Paragen" burner does give practical freedom from decarburisation with a surface finish which, while not bright, is acceptable commercially and is reasonably free from scale.

The work described in this paper was undertaken in the Development Department of Messrs. Wild-Barfield Electric Furnaces, Ltd., and the author is indebted to the Directors of the Company for permission to publish this work.

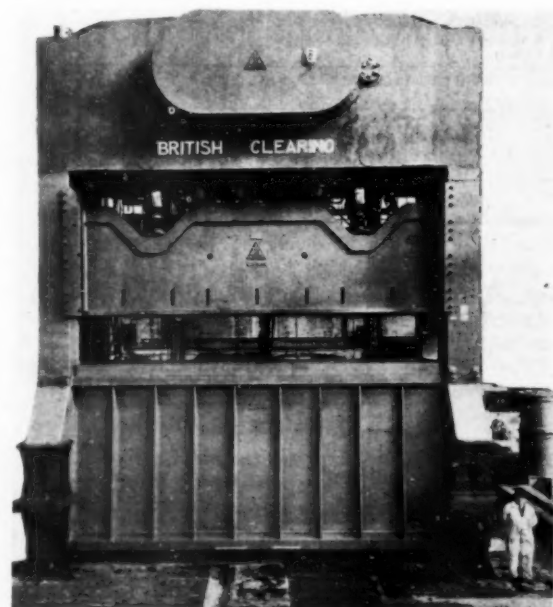
A Large Mechanical Press of Modern Design for British Industry

RECENTLY completed at the Elswick Works of Vickers-Armstrong Ltd., Newcastle-on-Tyne, is one of the largest mechanical presses built by the Company in conjunction with the Clearing Machine Corporation, Chicago, U.S.A. This machine is notable not only for its size (35 feet overall height, 25 feet between uprights, 220 tons weight), but is an outstanding example of modern press design applied to meet the requirements of high capacity and accurate operation. Having a capacity of 2,000 tons, this single action crankless press is designed for the manufacture of heavy road vehicle chassis frames, and embodies many features of construction of particular interest.

The separate frame members comprising bed, uprights and crown are of all welded steel construction, the largest fabrication being that of the bed which alone weighs 62 tons. Four massive steel tie rods secure the frame members; and the slide, which is also fabricated, is suspended from two plungers housed in the crown through which they are guided in bronze bearings. Precise alignment is assured by the provision of four individually adjustable gibs. The plungers are operated by bronze lined steel eccentrics which are cast integral with the driving gears. These gears together with their driving pinions, all cut from solid, are totally enclosed in the crown where they run in an oil bath. This ensures efficient lubrication and the exclusion of dirt and dust.

Drive from the operating motor is by V belt to a balanced flywheel driving a friction type, air operated, electrically controlled clutch. All main bearings are bronze lined steel castings welded to the steel plate fabrication of the crown, and lubricated by an electrically driven high speed pump drawing its supply from the crown oil bath.

Important additional features are embodied in this press. A power operated slide adjustment by an independent 10 h.p. motor, located within the slide, through bevel gears and massive adjusting screws gives a maximum adjustment of 20 in. Five air operated die cushions are accommodated in the bed. These cushions are guided for the full length of stroke, which ensures accurate operation. Each is provided with bronze wear strips and is capable of absorbing a pressure of approximately 80 tons at a working pressure of 100 lbs. per square inch, giving a total cushion capacity of 400 tons.



Large clearing press for making heavy road vehicle chassis frames.

Slide and die counterbalance is provided by four counterbalance cylinders located in the crown. These can be seen in the accompanying illustration, which also shows the slide plungers and bevel gears for power adjustment.

The all-electric clutch control embodies a rotary type cam limit switch, contactor panel and selector switches, which control the press through four cycles of operation by means of push buttons.

A brief specification of the press is as follows :—

Type	F.22000-300
Capacity	2,000 tons
Distance between uprights	300 in.
Stroke of Slide	18 in.
Adjustment of Slide	20 in.
Area of Slide	F to R and R to L. 30 in. x 290 in.
Area of Bed	F to B and R to L. 64 in. x 300 in.
Bed opening	F to B and R to L. 40 in. x 284 in.
(five openings, four ribs).	
Shut Height, Slide Stroke down adjustment up	36 in.
Operating Motor	75 h.p. x 1,500 r.p.m.
Strokes per minute	6

Large numbers of British clearing presses, single, double and triple action, covering a wide range of capacities, are at present being built by Vickers-Armstrongs Ltd. for customers both at home and abroad.

Mobile Laboratory to aid Increased Steel Production

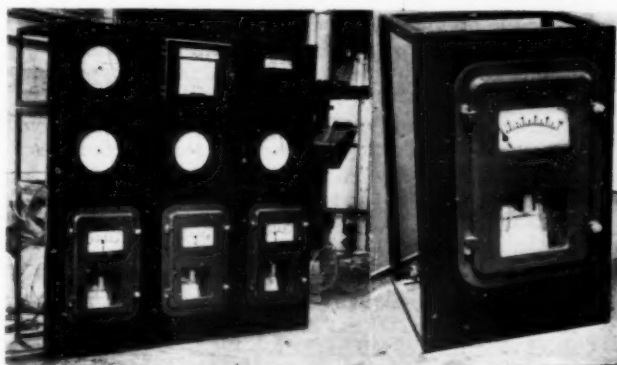
ONE of the difficulties in applying the results of research to industry is that of giving confidence of the advantages of a particular application. A solution to such a difficulty is a mobile laboratory and office designed for "field" operation in iron and steel works, which has been recently built by the Steelmaking Division of the British Iron and Steel Research Association. Mounted on a 3-ton ex-army truck (formerly a telecommunications van), as will be noted in the accompanying illustration, a box body contains the laboratory instruments, and can be lifted off the chassis by crane and transported to otherwise inaccessible parts of the works.



The mobile laboratory.

Since various combinations of instruments may be wanted in different circumstances, each item is mounted separately in a light-weight panel and assembled on a frame to form a standard unit. Two standard frame sizes are used to provide further flexibility, one being half the size of the other. The removable body is fitted in addition with small laboratory and workshop benches, writing table, cupboards, field telephones, lighting and air conditioning. Thus it can also be used as a central office for works trials.

The actual instruments comprising the equipment are: Ring balance flow meters of various ranges; indicating and recording potentiometers; indicating and recording millivoltmeters; total radiation pyrometers; thermocouples; gas analysis apparatus;



Unit-type instrument panel set up in works.

One of the instrument units.

CO₂ recorders; pressure recorders; and immersion pyrometer for liquid steel temperatures.

Increased Production

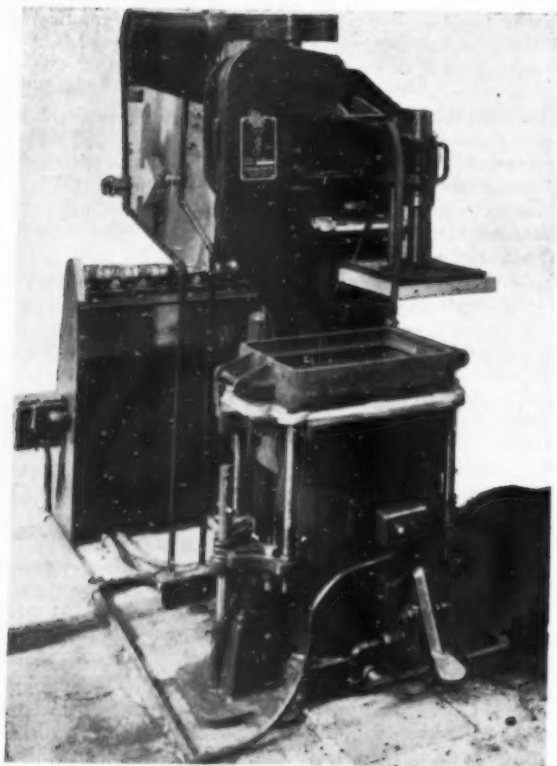
The operators of this mobile laboratory can thus make accurate measurement and record of the fuel flow and composition, the flue gas analysis and the thermal and pressure conditions within a steel furnace in actual operation. By the installation and proper use of permanent instruments such as these many steel works have secured output increases in the order of 10% and 20%, and one of the purposes of this mobile laboratory is to enable works not yet so equipped to benefit from the experience of others when planning their own installations. Another function is to make possible field work on the scale necessary for the furtherance of these encouraging results. Hitherto, collection of essential data from works not yet fully instrumented has involved the loss of much time in the siting, collection and erection of instruments. Now the whole installation can be completed in a matter of hours.

The mobile outfit has been designed by Dr. A. H. Leckie, Deputy Head of the Steelmaking Division, and Mr. E. Rogers, officer in charge of Instruments for the Division, and was assembled at the Association's Physics Laboratories, Battersea. It will be used in works trials throughout the country. Works staff interested in making use of the equipment are invited to contact Dr. Leckie at the Association's Headquarters, 11, Park Lane, London, W.1, as although a full initial programme has been arranged, the nature of the work undertaken at a later date, and possible further extensions, will be substantially affected by the industry's own requirements.

An Automatic Moulding Machine

AN entirely new conception of mould production for castings is opened up by the development of an automatic moulding machine, which is claimed to be the first of its kind to be applied. Hitherto every moulding machine has required its individual operator, and output has been dependent on a series of manual operations. Such limitations in no way apply to this new machine in which the full cycle of operations automatically follow in their correct sequence on the pressing of a push button.

The logical outcome of this development is battery operation, with opportunity for very marked economy in labour. One such battery might consist of, say, eight of these machines in line, with empty boxes brought to the machines by pendulum conveyors from the knock-out station, with sand brought by overhead hoppers, and with the finished moulds taken away by conveyors. Two operators could handle such a battery—one transferring boxes to the machines and merely pressing the starting push button of each, and the other removing completed moulds on to the conveyors. Another scheme might be represented by a battery of four machines around a rotating disc fed with sand through an overhead hopper, the sand being automatically ploughed off the disc into the boxes on tables of the machines. With such an arrangement one attendant might reasonably keep four machines in



A moulding machine with control unit for automatic operation.

constant operation. The whole would constitute a small mechanised foundry unit, complete in itself, of high productivity, inexpensive to instal and remarkably economic in operation.

Definite operational times are maintained from mould to mould as a function of the machine, and without any sense of effort or strain. The maintenance of this time cycle ensures absolute uniformity of ramming and consistency of moulds, irrespective of the human element. When the operator pushes the starting button, the motor-driven control unit comes into operation and takes complete charge until the cycle of moulding operations has been completed—after which the motor is automatically knocked off. The actuating element in the control unit is a cam shaft carrying a series of small cams, beneath which is a rocker shaft carrying a corresponding row of rockers. Then at a lower level is a row of pneumatic valves each operated by the rocker above it. Each valve controls the inlet and exhaust of compressed air to and from the machine for the starting and stopping of each operation in the sequence required to produce a finished mould.

These operations are: filling the box with sand; swinghead brought over the table and the jolting commenced; jolting continued simultaneously with squeezing; the squeeze is exhausted and the swinghead starts to move away from the table; vibrating; pattern draw; motor knock-off. At the conclusion of this cycle of automatically controlled operations the completed mould is ready to be removed from the table.

As will be noted in the accompanying illustration, the control unit, which can be located at any distance

from the machine, is robust and it gives simplicity of operation. In suitable circumstances one such unit can be arranged to control a battery of machines. In view of its labour-saving possibilities, this development is of more than ordinary interest under prevailing foundry conditions. It is a product of Messrs. Stone-Wallwork Ltd., 157, Victoria Street, London, S.W.1, who will supply any further information concerning it that may be desired.

Staff Changes and Appointments

MR. L. H. COOPER, a director of the Mond Nickel Company Ltd., has been elected assistant secretary and assistant treasurer of the International Nickel Company of Canada, Ltd. This appointment is additional to his present position in the Mond Nickel Company, and he will continue to be located in London. He joined the Mond Nickel Company, Ltd., in 1926 and was secretary of the Company for eleven years prior to his election to the Board in 1945.

SIR ALEXANDER DUNBAR, who last year retired from the board of the English Steel Corporation Ltd., has joined the board of the Projectile and Engineering Co. Ltd.

DR. J. R. RAIT has been appointed research controller of Messrs. Hadfields Ltd. Since 1943 he has been manager of the melting departments of Wm. Jessop and Sons, Ltd.

MR. WILLIAM B. BROOKS has resigned his position with Alloys Development Company and has established a consulting practice specialising in stainless and alloy steels.

MR. H. T. PARISH has been appointed a director of Messrs. Christmas and Walters Ltd., steelworks engineers and gas producer specialists. He will continue his duties as secretary of the Company.

MR. CYRIL CROXFORD has been appointed general manager of Llanelly Steel Co. Ltd. and has resigned his position as steelworks manager at Guest Keen Baldwins Iron and Steel Co. Ltd., Cardiff.

MISS J. U. SPELLMAN has been appointed librarian to the Copper Development Association. She was formerly in charge of the research department library of Electrical and Musical Industries Ltd. It is noteworthy that the Association's library has been expanding at a considerable rate for many years past, and now comprises one of the most valuable collections in existence of carefully selected technical information on copper and its many applications.

THE board of the Steel Company of Wales Ltd. have appointed the following directors to executive positions: Mr. E. J. Pode, managing director; Captain H. L. Davies, assistant managing director; Mr. W. F. Cartwright, general manager, steel division; Mr. T. O. Lewis, general manager, tinplate division.

MR. G. SMELLIE, formerly deputy works manager of the Port Talbot Works, has been appointed works manager in charge of the Margam and Port Talbot Works of the Steel Company of Wales, Ltd.

MR. D. M. LEWIS has joined the staff of the British Iron and Steel Research Association and will work in the Physics Laboratory at Battersea.

Continued on page 338

Modern Methods of Gas Analysis

Part VI.—The Haldane Apparatus—contd.

By W. D. Vint

Method of Checking Burette

CONSIDERABLE errors may arise from a badly calibrated gas burette and the very first operation after the purchase of such an apparatus should be the performance of a thorough test upon the burette. This may be done in either of two ways.

(1) Disconnect the burette from the rest of the apparatus and slip off the rubber tubing at the bottom which leads to the mercury reservoir. An ordinary glass tap can now be temporarily fused to the bottom of the burette which is now filled with clean refined mercury. By means of the tap volumes of mercury corresponding to certain graduations on the burette may be tapped out and accurately weighed. From a knowledge of the specific gravity of the mercury the exact volume which has been tapped can be calculated and should correspond with the volume as indicated by the burette; each graduation should be checked in this manner as it is feasible for one or more of the graduations to be incorrect.

(2) An easier method of checking the burette is by the analysis of a sample of outside air. Fortunately, nature has furnished us with an atmosphere of practically constant gas composition so that by the analysis of an air from practically any locality the graduations may be checked.

The two constituents of the atmosphere which afford the requisites for the calibration are carbon dioxide and oxygen. Although these do vary slightly in different districts and under different conditions their sum is fairly constant and amounts to 29.96%. About four or five samples of an outdoor air should be analysed and the mean calculated for carbon dioxide and oxygen. The addition of the two should give a figure 29.96% plus or minus 0.05%. This test however, does not ensure that the graduations on the lower part of the burette are correct, the discrepancies of which may be quite considerable. They may be checked as follows: Fill the burette with air to near the bottom of the graduations and observe the reading, taking the usual precautions. Now shut about one cc. into the com-

bustion pipette (which must have previously been brought to the correct mark) and read the burette again. The difference between the two readings gives the exact volume of the air. About one cc. is now expelled to the atmosphere and the burette again read. The measured volume of air is now returned from the combustion pipette and another reading taken. If the graduation is even, the volume of air should read exactly the same as it did before on the lower part of the burette. The process may be repeated all the way up the graduated part of the burette. If there are any marked signs of irregularity in the graduations the burette should be instantly rejected.

Maintenance of the Apparatus

After an analysis, the burette should be isolated by closing taps C and S and the control tube J opened to atmosphere by the tap L. The nitrogen left over from an analysis should be retained and stored over the pyrogallate solution; it can then be used in the next analysis to clear the capillaries of oxygen.

The burette should be cleaned with dilute nitric acid whenever it begins to get dirty. The excess nitric acid must then be washed away with water and a small amount of dilute sulphuric acid added. Should either of the caustic solutions in the carbon dioxide or oxygen pipettes be accidentally drawn up as far as the tap and perhaps even into the burette, the whole of the affected parts must be washed through with water and moistened with dilute sulphuric acid. If this precaution is not carried out the taps are sure to stick and if left long enough may even necessitate cutting out. The taps are now cleaned in cold water, wiped dry, and lightly smeared with tap grease. The seatings also are cleaned and dried and the taps inserted.

Owing to the high accuracy which is possible on this apparatus it needs but a very slight leak in one of the connections to give rise to considerably inaccurate figures. Badly ground taps are also

subject to leakages and in such cases must be removed. To test for leakages, heavy pressures must be brought to bear upon the affected joints in succession and this is best done as follows:—

The tap L should be turned to shut off connection with the control tube. The rubber tube connecting the potash reservoir and pipette must now be squeezed firmly and any leakage present will be indicated by the liquid creeping above the mark K. Other connections between pyrogallate and combustion pipettes are tested in a similar manner and leaky connections to taps replaced.

A possible source of error concerning the CO₂ determination is, that when freshly made, the KOH may dissolve a little sulphide from sulphur present in the rubber. The K₂S thus formed may eventually dissolve oxygen from the sample and a high false reading is thus obtained for the CO₂. The presence of sulphide in the KOH is sometimes evidenced by a yellow colour and under such circumstances the KOH should be immediately changed. The use of black rubber tubing for this particular connection removes any possibility of errors.

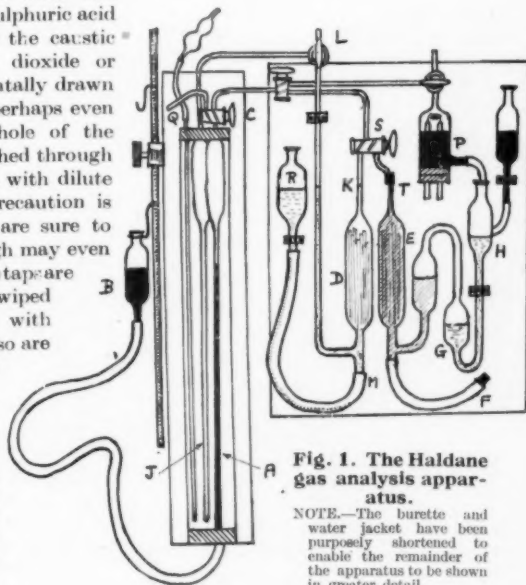


Fig. 1. The Haldane gas analysis apparatus.

NOTE.—The burette and water jacket have been purposely shortened to enable the remainder of the apparatus to be shown in greater detail.

The efficiency of the apparatus may be ascertained by sampling and analysing fresh air. After the CO_2 has been absorbed, the gas should be passed into the combustion pipette and the spiral brought to a red heat. After passing the gas repeatedly over the spiral, the current is switched off and the apparatus allowed to cool down. The gas is now transferred to the burette and a reading taken. There should be no difference between this reading and the one taken before the gas was passed over the spiral. The gas may now be passed several times into the KOH pipette and the reading now observed should likewise show no difference. After absorption has been made in the pyrogallate solution and a constant reading obtained, the percentage of CO_2 and O_2 are calculated their sum should be a constant no matter how many analyses of the air are made.

Before any analysis of a gaseous mixture other than air is made, the apparatus should be tested in this manner.

Analyses of More Complex Gaseous Mixtures

In the last issue of this series, the procedure for dealing with the analysis of a simple mixture of CO_2 , O_2 and N_2 was outlined. The procedure adopted for the examination of a mixture containing one or more combustible gas in addition to the CO_2 , O_2 and N_2 normally present is as follows:—

A choice of two methods is available depending upon the approximate proportions of O_2 to combustible gases present in the sample. If sufficient O_2 is present to completely burn the combustible gas the CO_2 is firstly eliminated in the usual manner and the gas then passed into the combustion pipette and current switched on. After combustion is complete the gas is remeasured in the burette. The processes of combustion and elimination of CO_2 are repeated until constant readings are obtained on the burette. The capillaries to the combustion pipette are swept and the remainder of the CO_2 absorbed in KOH.

A separate determination for O_2 is made on the sample contained by the sampling tube. The CO_2 which of course, must be eliminated in the usual manner provides a useful check on the original CO_2 estimation. A typical set of readings taken during an analysis of a gaseous mixture containing CO_2 , O_2 , CH_4 , H_2 and N_2 is recorded as follows.

Mixture of CO_2 , O_2 , CH_4 , H_2 and N_2 (Oxygen in sufficient quantity to burn CH_4 and H_2)	
Initial Volume of Sample	20.129 cc.
After CO_2 absorption	20.084 cc.
First Contraction	19.730 cc.
After CO_2 absorption	19.686 cc.
Second Contraction	19.633 cc.
After CO_2 absorption	19.626 cc.
Third Contraction	19.617 cc.
After CO_2 absorption	19.615 cc.
Fourth Contraction	19.615 cc.
After CO_2 absorption	19.615 cc.
Therefore Total Contraction	0.416 cc.
And Total CO_2 formed	0.053 cc.
CO_2 is $\frac{0.045}{20.129} \times 100 = 0.22\%$	
CH_4 is $\frac{0.053}{20.129} \times 100 = 0.26\%$	
H_2 is $\frac{(0.416 - 2 \times 0.053) \times 100}{20.129} = 1.03\%$	
Separate Determination for Oxygen.	
Initial Volume of Sample	20.254 cc.
After CO_2 absorption	20.210 cc.
After O_2 absorption	16.958 cc.
CO_2 is 0.21%	
O_2 is $\frac{20.210 - 16.958}{20.244} \times 100 = 16.07\%$	
Complete Analysis is: CO_2 .. 0.22%	
O_2 .. 16.07%	
CH_4 .. 0.26%	
H_2 .. 1.03%	
N_2 .. 82.42%	
	100.00%

If insufficient oxygen is present in the sample itself to combine with the combustible gases, the procedure is as follows:—

CO_2 and O_2 are estimated in the usual manner on about 20 cc. of sample and the residual gas discarded. The KOH and pyrogallate capillaries are now swept with air which is then passed into the combustion pipette and burnt to remove the traces of combustible gases. Oxygen is now eliminated by passing repeatedly into the pyro pipette and all the capillaries are also swept clear of oxygen. After the apparatus has then been levelled up, a certain quantity of the sample is admitted to the burette. A knowledge of the approximate percentages of the combustible gases in the sample is necessary and the appropriate quantity of oxygen or air required for complete combustion (with a certain excess) is now added to bring the volume to a total of about 20 cc. The CO_2 is now absorbed by passing into the KOH. The mixture is completely burnt in the combustion pipette and the CO_2 formed is absorbed.

Several other combustions are carried out with subsequent CO_2 absorptions until constant readings are obtained on the burette. A typical set of results are recorded as follows:—

Mixture of CO_2 , O_2 , CH_4 , H_2 and N_2 (Oxygen in insufficient quantity to burn CH_4 and H_2)	
ESTIMATION OF CO_2 AND O_2	
Initial Volume of Gas Sample ..	20.244 cc.
After CO_2 absorption	19.386 cc.
After O_2 absorption	19.290 cc.
CO_2 is $\frac{0.858}{20.244} \times 100 = 4.24\%$	
O_2 is $\frac{0.096}{20.244} \times 100 = 0.47\%$	
ESTIMATION OF COMBUSTION GASES.	
Initial Volume of Gas Sample ..	15.608 cc.
Volume of Gas plus Air Added ..	20.345 cc.

After CO_2 absorption	19.681 cc.
First Contraction	18.542 cc.
CO_2 absorption	18.362 cc.
Second Contraction	18.100 cc.
CO_2 absorption	18.078 cc.
Third Contraction	18.065 cc.
CO_2 absorption	18.063 cc.
Fourth contraction	18.062 cc.
CO_2 absorption	18.061 cc.
Total Contraction is 1.415 cc.	
Total CO_2 formed is 0.205 cc.	
CH_4 is $\frac{0.205}{15.608} \times 100 = 1.31\%$	
H_2 is $\frac{(1.415 - 2 \times 0.205)}{15.608} \times 100 = 4.29\%$	
Therefore Complete Analysis is CO_2 4.24%	
O_2 0.47%	
CH_4 1.31%	
H_2 4.29%	
N_2 89.69%	
	100.00%

The foregoing examples indicate the procedure and calculation of gaseous mixtures containing CO_2 , O_2 , CH_4 , H_2 and N_2 . Should CO be present instead of the H_2 or CH_4 , the analysis is exactly the same but the calculation of results follows that as described for the analysis of blast furnace gas on the Orsat apparatus.

When three combustible gases (usually CH_4 , CO and H_2) are present, the best method is to determine the CO separately on another apparatus (above 0.5% on the Bone and Wheeler or Orsat, below 0.5% on the Graham Lawrence) and carry out the analysis as already described on the Haldane. Readings taken of this type of analysis are shown as follows:—

Mixture of CO_2 , O_2 , CO, CH_4 , H_2 and N_2 Estimation of CO on Graham-Lawrence Apparatus	
Volume of Gas Sample	20.012 cc.
After CO_2 absorption	19.804 cc.
Therefore CO_2	1.04%
Total Contraction	0.426 cc.
Total CO_2 formed	0.098 cc.
0.098 cc. represents the CO_2 formed by the combustion of CH_4 and CO.	
The Volume of CO_2 produced by the combustion of CO alone would be:—	
$\frac{0.07}{100} \times 20.012 = 0.014$ cc.	
Therefore CO_2 formed by combustion of CH_4 alone was 0.098 — 0.014 which is 0.084 cc.	
Therefore CH_4 equals $\frac{0.084}{20.012} \times 100 = 0.42\%$	
The contraction minus $\frac{1}{2}$ the CO_2 produced by the burning of the CO is the contraction due to the combustion of the CH_4 and H_2 which is 0.426 — 0.007 equals 0.419 cc.	
The contraction due to CH_4 is 2×0.084 cc. and equals 0.168 cc.	
Therefore the contraction due to H_2 alone is 0.419 — 0.168 and equals 0.251 cc.	
Thus H_2 is $\frac{0.251}{20.012} \times 100 = 0.84\%$	
O_2 determination on separate sample is	15.43%
Therefore Complete Analysis of Gas	
CO_2 1.04%	
O_2 15.43%	
CO 0.07%	
CH_4 0.42%	
H_2 0.84%	
N_2 82.20%	
	100.00%

There is practically no limit to the usefulness of the Haldane apparatus. The instrument is invaluable for checking the comparatively small percentages of H_2 , CH_4 or CO, etc., in protective atmospheres and for the estimation of gaseous impurities in cylinders of hydrogen, oxygen, etc.

Hydrogen, Nitrogen and Oxygen in Ferrous Metals

Their Properties and their Determination—Part I

By E. C. Pigott

A very extensive literature exists on the gaseous constituents of irons, steels and ferro-alloys. Over a period of many years leading chemists and metallurgists have been engaged in piecing together the intricate facts brought to light. It would now seem that the main experimental and co-ordinating work has been done and that a clear perspective of this once totally obscure field has become possible. In this and subsequent articles the author presents such a perspective.

Hydrogen

At. Wt. : 1.008 (weighted mean of H^1 , H^2 (deuterium) and H^3 (tritium)).

M. Pt. : $-259.14^\circ C$.

B. Pt. : $-252.78^\circ C$.

Density at N.T.P. (water=unity) : 0.0000899.

(air=unity) : 0.069 (liquid, 0.071).

Weight of 1 litre : 0.08987 g.

Solubility (100 vols. water, $20^\circ C$.): 1.84 vols.

Oxides : H_2O , H_2O_2 .

Forms : Molecular (ortho and para allotropes), atomic, triatomic.

Discovery : Identified as distinct substance in 1766 by Cavendish.

Extraction

Although minute traces of free hydrogen are present in the atmosphere, the element commonly exists in the combined form : for example, in water, in many gases, and in nearly all organic substances. The most important source is as a by-product of the electrolytic manufacture of caustic soda from sodium chloride. Large quantities are extracted from water gas by the Bosch and Lane processes. Displacement from mineral acids by zinc, iron, tin, etc., is also exploited.

Chemical Properties

Hydrogen, comparable in some respects with the metals, is a colourless, tasteless, odourless gas that is combustible, though it does not support combustion, and is non-poisonous, though it does not support respiration. So markedly does the atomic structure differ from that of other elements that hydrogen fails to fit properly into the general scheme of the periodic system. The ordinary gas is itself composed of two distinct allotropic forms, parahydrogen and orthohydrogen, in the proportions 1 : 3. In the molecule of the former, the two atomic nuclei rotate in the same direction, while in the latter they rotate in opposite directions : consequently the two forms differ in certain physical properties, having, for example, different specific heats, and boiling points of 20.26° and 20.43° abs. respectively. Parahydrogen may be isolated by adsorption of ordinary hydrogen on charcoal at the temperature of liquid hydrogen. Reversion to the ordinary state is catalysed by metals, since they absorb hydrogen atom by atom and reunion soon takes place.

At temperatures above $2,000^\circ$ abs. hydrogen dissociates into single atoms. The splitting is facilitated by decreased pressure and is strongly endothermic. Molecular hydrogen is not at ordinary temperatures a particularly active gas, but the atomic form is highly reactive, forming hydrides with sulphur, phosphorus and arsenic, oxidising hydrogen bromide to bromine, and reducing oxides—even tungstic oxide—and salts to the metal. The atoms very readily diffuse to the cool walls of a vessel, where they are adsorbed and recombined. So great is the heat of recombination that it is utilised for welding, the hydrogen gas being fed through an electric arc struck between tungsten poles ; when the atoms reunite on the surface of the object temperatures sufficiently high to melt tungsten ($3,400^\circ C$.) tantalum, etc., are obtained. There is proof of the old assumption that nascent hydrogen, the reducing powers of which are so analytically useful, is in the atomic state, though part of its pronounced reactivity may be due to the great internal pressure characteristic of very minute bubbles.

Triatomic hydrogen, H_3 (hyzone) which is rather more stable than triatomic nitrogen, is produced in the form of its positive ion H_3^+ when a glow discharge is passed through a mixture of ordinary hydrogen and water vapour.

Recent knowledge of atomic structure suggests that all elements may be composed of hydrogen atoms or helium or both ; bombardment with X-rays causes evolution of hydrogen from a large number of elements. The visible spectrum of hydrogen is more simple than that of most elements and contains a series of prominent lines interspersed with fine lines. In the electrometric potentials system of the elements, which indicates their relative affinities for positive electricity as well as their relative oxidising and reducing capacities, hydrogen serves as a convenient zero point and the voltages commonly tabulated are those obtained by measurement against a normal hydrogen electrode. Hydrogen ions surrender their positive charge to any element preceding it in the series and the wider the positional separation the greater is the discharging tendency.

Little or no hydrogen is liberated by the action of concentrated acids on metals. Increase in speed of the solvent action of acids produced by rise of temperature is chiefly due to the lower viscosity of hot liquids. The weaker the acid the more readily is a protective film formed since the salts of very weak acids are almost completely hydrolysed in solution.

Hydrogen is only sparingly soluble in water, 100 volumes of which dissolve 1.84 volumes at room temperature. The gas completely reduces hot oxides of iron, lead, nickel, copper, etc., to metals: the ease with which oxides or other compounds are reduced to metals increases as they approach the noble metals. Many vapourised substances undergo reduction when passed with hydrogen over finely divided nickel. Hydrogen under pressure precipitates from aqueous solution those metals having less tendency to ionise than hydrogen itself—e.g., Hg, Cu, Co, Ni, Pb, Bi, but not Fe or Zn. When the acid formed becomes sufficiently concentrated to attack the metal, the reaction comes to a standstill.

Identification

Free hydrogen may be identified by its almost colourless flame, the combustion yielding a residual gas free from carbon dioxide. Small amounts in gaseous mixtures may be detected by absorption in spongy palladium from which it may be recovered by the action of heat. Combined hydrogen is best detected by heating the suspected compound with copper oxide, which in most cases oxidises the element to water.

Oxides: Water

Heated in the presence of oxygen, hydrogen burns with a very hot flame, the product being water. The two gases begin to react at about 300°C., the rate increasing rapidly with increase in temperature and decreasing with excess of oxygen. Unless perfectly dry, mixtures explode violently if ignited, a minute electric spark in a small fraction being sufficient to start explosion of the whole. The reaction is catalysed by platinum, cobalt, nickel, iron, etc., and if platinum black is used, union occurs at room temperature.

Pure water, the best of all ionising solvents, itself contains a small quantity of hydrogen ions together with an equivalent quantity of hydroxyl ions. Discharge of the hydrogen atoms by interaction of the water with electropositive metals may be accelerated by decreasing the number of hydroxyl ions—e.g., by adding an acid or ammonium chloride. Liquid water is believed to be somewhat polymerised, loose aggregations of water molecules being continually formed and decomposed.

Water is decomposed at room temperature by the alkali metals and alkaline earth metals, while magnesium zinc and iron readily react with steam. Generally, water does not react with non-metals, exceptions being carbon, silicon, fluorine and chlorine. Water usually hydrolyses salts derived from acids and bases of markedly different strengths. The catalytic action of water, especially when slightly impure, is remarkable; the effects of complete drying in greatly retarding the combustion of carbon monoxide and in inhibiting the reaction between ammonia and hydrogen chloride are but two of many examples.

Since the water molecule contains two "lone-pairs" of electrons, which can form co-ordinate linkages, water displays a strong tendency to react to form additive compounds of which the most important are the hydrates.

Deuterium, D, the hydrogen isotope of mass 2, is present in ordinary hydrogen to the extent of one part in 30,000. It is a colourless inflammable gas practically identical with hydrogen in all chemical properties, but somewhat less reactive. In combination as heavy water, D₂O, it accumulates in the residual water left on electrolysis. Heavy water is chemically similar to ordinary water, but differs markedly in physical properties—e.g.,

S.G. 1.056, M. Pt. 3.8°C., B. Pt. 101.42°C. The yield from the electrolysis of 100 gallons of water is about 1 ml. It may be obtained also by fractional distillation. Some substances dissolve to a smaller extent in heavy water than in light water. A ready interchange of the atoms of the two hydrogen isotopes takes place between solute and solvent. The ionic mobility of heavy water is less than that of ordinary water. The proportion of tritium, H₃, in ordinary water is merely 7 parts in 10¹⁰.

Hydrogen Peroxide

Most of the large variety of processes by which hydrogen peroxide may be prepared are based on electrolysis or on the decomposition of barium peroxide or sodium peroxide. It can be concentrated by removal of the water under reduced pressure, and still further concentrated by freezing and fractional liquefaction at -8° to -10°C. The pure viscous liquid is fairly stable, has a specific gravity at 0°C. of 1.458, boils at 68°C. under a pressure of 26 mm., freezes in the form of needle-like prisms at -2°C. and mixes with water in all proportions. Dilute aqueous solutions slowly undergo decomposition, a change hindered by acetanilide, acids, glycerol, alcohol, ether, etc., and promoted by rough surfaces and by impurities such as silica, iron and manganese. Solutions of hydrogen peroxide are marketed in strengths expressed according to the number of volumes of oxygen furnished by each ml, a "10-volume" solution containing about 3% of hydrogen peroxide and the most concentrated commercial form, "100-volume" solution, about 30%. In its powerful oxidising properties, hydrogen peroxide resembles ozone. It readily oxidises ferrous solutions to ferric, sulphites to sulphates, etc. Strictly, the reducing properties are merely apparent and arise from the readiness with which the odd atom of oxygen is surrendered to combine with some oxygen atom readily disengaged from its combination. Three highly specific tests are the liberation of iodine from potassium iodide in the presence of ferrous sulphate, the action on titanium sulphate, and that on potassium dichromate, preferably in the presence of ether. Other tests may be misleading in that a number respond also to ozone, chlorine and nitrogen peroxide.

Absorption and Reactivity

Many of the heavy metals—e.g., Fe, Cu, Ni, Pt, Pd, Ta absorb hydrogen, thereby assuming alloy characteristics. The hydrogen in them is not chemically combined: it is present in the monatomic condition and behaves as a metal. With appreciable quantities of absorbed hydrogen, the volume is greater and the alloys have less mechanical rigidity and disintegrate more readily. Electrolytically deposited iron and palladium contain respectively more than 100 times and 1,000 times their volume of hydrogen. With many metals, hydrogen does not chemically react. Magnesium and beryllium and the more strongly basic rare earths excepted, the alkali and alkaline-earth metals form somewhat unstable white crystalline hydrides on heating with hydrogen—e.g., NaH, KH, CaH₂. These are among the most reactive of substances: on addition of water, they yield hydrogen and the metallic hydroxide, and they reduce CO₂ to carbon.

The elements comprising the "b" sub-groups in groups IV-VII of the periodic system, as well as boron, all form non-polar gaseous hydrides. The silicon and boron compounds resemble antimony and arsenic hydrides and are inert to many reagents including

concentrated sulphuric acid. Tin hydride is unaffected by dilute alkalis and concentrated nitric acid. The sulphur, selenium and tellurium compounds, H_2S , H_2Se , H_2Te are formed at 250°–400° C. Fluorine reacts explosively; chlorine reacts at ordinary temperatures if exposed to light: both bromine and iodine react above 400° C. The bromide, iodide, and chloride are colourless gases: the fluoride is a limpid liquid. All are extremely soluble in water, the constant boiling liquids containing respectively 48% HBr, 57% HI, 20–24% HCl, and 36% HF. Pure carbon does not react appreciably except at high temperatures in the presence of a catalyst when methane, CH_4 (1,150° C.) is formed and, at very high (arc) temperatures, acetylene, C_2H_2 .

Consideration of Methods

A considerable amount of research has been directed in this country, the United States, and elsewhere towards accurate estimation of the element in iron and steel. When it is realised that contents as low as 0.0001% begin to have metallurgical significance it will be seen that workers bent on devising dependable procedures were beset with no mean problem.

In general, the hydrogen content of molten or newly cast steel is appreciably higher than that of stored steel, but does not diminish to any extent after the first month, when, however, the residual content can be as much as 0.0003% for a carbon steel or 0.001% for a chromium steel. Although the length of time preceding the determination gradually ceases to be of consequence, it is a good rule to carry out the determination as soon as possible after receipt of samples.

The reduction in content brought about by hot working is very great. After much hot rolling *very little* of the hydrogen remains. Some $\frac{3}{4}$ -in. bar rolled from an ingot containing 0.00035% was found to contain less than 0.0001%, a typical diminution.

The inside of a section is invariably higher in hydrogen than the outer portions, and wide content variations in specimens are by no means uncommon. A five-fold variation between the centre and outside of a small ingot has been reported. Large and small sections (as cast) from the same ladle have different hydrogen contents. There is no doubt, however, that some reported variations are largely the result of incorrect sampling. During the course of machining, every care must be taken to avoid appreciable heating, while operations such as sawing and grinding must be performed very slowly. Further, dry conditions have to be maintained. When liquid steel is sampled for its hydrogen content it is more than ever important that the sampling apparatus should be kept in a rigorously dry condition.

Although the amounts of hydrogen contained in iron and steel are usually infinitesimal in relation to those met with in ordinary gas analysis, mention of classical methods is called for here because they are exploited, on a micro scale, in conjunction with the special methods applied to iron and steel. The commonest classical method is that of first removing such gases as are readily retained in ordinary liquid absorbents and then sparking the residual hydrogen in excess of oxygen using an explosion bulb fitted with a platinum-wire spark gap connected with an induction coil or magneto. The hydrogen combines to the extent of one half its volume, and since the volume occupied by the water formed is negligible, the hydrogen content is readily calculated from the shrinkage. Methods in which the hydrogen is

itself caused to be absorbed are usually less satisfactory. The best absorbents are metallic palladium and a 1% solution of palladous chloride. Metallic palladium removes the hydrogen partly by absorption and partly by catalytic combustion. Any carbon monoxide or methane present may also undergo partial oxidation; the carbon dioxide formed may be determined and a correction made. In this direct absorption process, it is advisable to use a fractional combustion "pipette."

A method sometimes applied to cast iron is that of direct ignition in oxygen with absorption in a phosphorus pentoxide tube of the resultant water, but this is seldom applicable to the low contents commonly present in commercial steel. Naturally, aqueous chemical processes are altogether inapplicable. Ageing at room temperature has been employed but the yield is necessarily incomplete.

The method most generally used is that of vacuum extraction at elevated temperatures below melting point, usually referred to as "hot-extraction," and the next most important is that of vacuum extraction at temperatures above melting point, usually termed "vacuum fusion."

Hot Extraction

The solution of hydrogen in α -iron is a reversible process that takes place rapidly at temperatures above 500° C. Much of the pioneer work was carried out by H. A. Sloman, who established that, normally, at 650° C. hydrogen was completely evolved within 1–2 hours. It has been found that the evolution rate attains a slight maximum at 600° C. at which temperature most plain and alloy samples yield all their hydrogen within an hour, 90% of the gas being collected in the first 30 mins. The extracted gas is free from all but traces of contaminating gases. Since the γ -lattice is less permeable than the α -lattice, the evolution rate at 600° C. of austenitic alloys is substantially slower than with ferritic steels, and while temperatures up to 850° C. yield an improvement the rate is still relatively sluggish, and it is considered preferable to carry out the determination even in these materials at the more normal temperature of 600°–650° C., even though this naturally takes longer. The method consists essentially in measuring the pressure of the extracted gas. Most determinators used in Britain are based on a simple type of glass apparatus designed by W. C. Newell (J.I.S.I., 1940, No. 1, 243P; 1943, No. 2, 287P), in which the sample, heated at 600° C. in a high vacuum, can be manipulated vertically in and out of a clear-silica-tube furnace either by the novel principle of a "mercury-lift" or magnetically, so avoiding contact and possible interaction between the sample and the furnace wall. The accuracy is of a very high order, and the blank is negligible, amounting to no more than 0.00001 ml. (i.e., 0.001%). Of several modifications of Newell's original apparatus, the one chosen for description here is that devised by Colbeck, and Craven (originally published in J.I.S.I., 1943, No. 2 298 p. and since improved). In this modified apparatus, simple magnetic control is used (non-magnetic samples are manipulated by means of a magnetic pusher), and there are advances in the pumping system and a reduction in the number of taps.

Vacuum Fusion

Where the necessary equipment happens to have been installed the method of vacuum fusion in a graphite

crucible coupled with volumetric measurement in a small Orsat apparatus, is also entirely satisfactory. Both apparatus and technique are more elaborate than with the hot extraction process, for the temperatures employed are of the order of 1,500°–2,000° C. Complete evolution of the hydrogen takes place within the first few minutes of fusion. In no case has the evolution of hydrogen been found to be either incomplete or sluggish even at temperatures as low as 1,550° C. For steel samples with a hydrogen content of not less than 0.0002% particularly, the results obtained are concordant with those given by hot-extraction. With lower contents the results tend to be vitiated somewhat by contamination and blank errors. The blank is about a hundred times as great as that in hot-extraction. The extracted gases may be analysed by means of selective freezing.

It has been established that when steel is melted in the presence of tin, a full evolution of hydrogen is obtained at the lowest temperatures used, and this modification in which the sample is melted with the tin in a quartz tube at 1,100°–1,200° C. has its advocates. A disadvantage is that tin is volatilised to cooler parts of the apparatus where it absorbs gas that is then difficult to extract.

Because of its rapidity, the vacuum fusion method is the one most frequently used for determining the hydrogen content of liquid steel. Clearly, it is specially desirable to know the content during the actual process of steelmaking. The hydrogen found in cold steel samples, especially small samples, often bears no relationship to that present in the molten metal. The average residual content of a large number of cold basic electric steel samples was 70% of the hydrogen content of the molten steel, but taken individually the ratios varied greatly. The sampling of liquid steel for its hydrogen content presents more difficulties than does sampling for its oxygen content. Of all substances hydrogen is the most volatile, and fixation at very high temperatures in the form of a stable compound appears not to be possible. Nor has it been found possible, even by special methods, to prevent the evolution of hydrogen from solidifying metal. Moreover, the refractory used must be impervious to the gas. Evacuated sampling containers, which serve well with other gases, are altogether unsuitable, since a vacuum has the effect of increasing the proportion of hydrogen evolved from the cooling metal.

A satisfactory sampling method has been devised by Hatfield and Newell (J.I.S.I., 1943, No. 2, 407 p.). By means of a novel balloon-tube device a small sample, taken from the furnace in a slagged spoon, is rapidly frozen and isolated under a constant pressure of one atmosphere of (nitrogen) gas, the loss of hydrogen, which is thereby minimized, being estimated and added to the content of the solid sample to give the content of the liquid steel. The previously deflated balloon receives the gas given off by the cooling steel. The gas collected from the tube consists of the nitrogen used (about 5 ml.) plus the escaped hydrogen (about 1 ml.) together with some carbon monoxide and oxygen. The last two are absorbed in ammoniacal cuprous chloride and the gas is then exploded with added oxygen. The solid cylindrical sample (6.5 in. in dia. and 0.5 in. in length) is transferred at once to the vacuum fusion apparatus.

So small are the hydrogen contents that they are sometimes expressed in terms other than those of direct

percentage—e.g., percentage times 10^4 ; atomic percentage; ml. at N.T.P. per 100 g. of sample; ml. at N.T.P. per ml. of sample.

When reporting results, it is advisable to state the time interval since casting, the thermal history of the section, and the position of the sample in the section.

To be continued

Staff Changes and Appointments

Continued from page 332

MR. R. M. PARRY has been appointed Managing Director of the British Driver Harris Company Ltd. MR. T. G. RUSSELL will retire from that position and will take up the duties of Vice-Chairman of the Company. MR. L. R. MATTHEWS has been appointed secretary.

MR. ROBERT R. GREGG, foundry manager of Reliance Regulator Co., Alhambra, California, has been elected an international director of American Foundrymen's Association. A native of the Isle of Man, Mr. Gregg began his career in iron works in the island, and went to America in 1907. He was appointed foundry foreman of the Steiger and Kerr Occidental Foundry, San Francisco in 1914, and subsequently became foundry foreman Hesse-Martin iron works, Portland, foundry superintendent Keystone Iron and Steel Co., Los Angeles, consultant and apprentice instructor Industrial Association of San Francisco. He joined Reliance Regulator Company in 1927 as foundry superintendent, and was advanced to foundry manager in 1940.

DR. H. G. TAYLOR, D.I.C., M.I.E.E., F.Inst.P., has been appointed Director of the British Welding Research Association. Born in Somerset and educated at Plymouth and Devonport Technical College, Barrow-in-Furness Technical School, Battersea Polytechnic and the City and Guilds (Engineering) College, he joined Vickers Ltd., at Barrow-in-Furness in 1921 as an apprentice electrician and after three years obtained the firm's scholarship, taking him to the University of London where he graduated, with First Class Honours in Electrical Engineering. A Royal Scholarship subsequently enabled him to take a year's post graduate research at the City and Guilds, as a result of which he was awarded the M.Sc. (Eng.) degree for a thesis on the collection of current from commutators and slip-rings. He then joined the Metropolitan-Vickers Electrical Co., as a College Apprentice, and was later posted to the Research Department. In 1929, he joined the staff of the Electrical Research Association to commence investigations on the subject of earthing. For his work on this subject he was awarded the degree of D.Sc. in Engineering by London University. In 1937, Dr. Taylor was appointed electrical engineer to the Copper Development Association, and it was with this association that he commenced his connection with the welding industry, which has continued since in his appointments of Technical Adviser to Philips Industrial and Manager of the Industrial Development Department of Philips Lamps Ltd., in which positions he has been, for the last five years, closely connected with Philips' activities in arc and resistance welding.

MR. JOHN WALKER has been appointed a Director of Morgan Crucible Co. Ltd.

SIR CLIFFORD PATERSON, O.B.E., F.R.S., has been appointed Chairman of the General Council of the British Standards Institution in succession to Sir William J. Larke, K.B.E.

The Effect of Notching on Materials of Construction under Static and Dynamic Tension*

(Maximum Testing Velocity 29 feet/second)

By Dr. Georges Welter,

Professor of Applied Mechanics, Ecole Polytechnique, Montreal.

This report discusses the results of static and dynamic tests performed in order to determine the effect of notches in specimens of various construction materials. The maximum initial testing velocity used was about 29 ft. per sec.

The properties of some light alloys and other structural materials were measured by comparing impact loading with static loading force-elongation diagrams recorded on a specially designed device. A tangential dynamometer with a spiral spring adjusted between steel strips records the dynamic load while simultaneously the elongation of the specimen is recorded by the rotating movement of a drum in a perpendicular direction. The maximum dynamic load that can be recorded by this device is about 3,000 lbs.

The total energy, the elongation and the energy absorbed per unit volume, for six different materials, were measured on specimens tested at a rate of straining of 0.005 ft. per second and compared with the same values measured on identical specimens strained about 20,000 times faster. As the volume and not only the section of the specimen or the structural member absorbs the applied load, it seems that the strength calculated per unit volume is a more reliable value than the strength calculated per unit section.

These tests confirm the conclusions reached in a previous investigation, to the effect that the dynamic strength of cylindrical 2 in. gauge length specimens,

at a speed of 11.78 ft. per second, is up to 60% higher than the static strength, depending on the material tested; in the case of zinc, it is 100% higher. At higher speeds, the ultimate strength is still increased. Furthermore, the notching effect under static and dynamic loads is very pronounced for all materials tested.

The dynamic as well as the static strength increases with decreasing gauge lengths, the amounts depending on the ductile properties of the material tested and the speed of the impact loads.

Notched specimens are very sensitive to impact loads at high speed, and even very ductile materials stand this test only in the annealed condition.

Most materials can be classified in three groups according to their behaviour under impact loads. The first group includes materials which are brittle at low impact speeds whether the specimen is cylindrical or notched. In the second group belong the materials whose strength and elongation increase with increasing speed when tested in the form of cylindrical specimens of at least $\frac{1}{2}$ in. gauge length; however, these materials are very sensitive to the introduction of a notch in the specimens, which checks the flow of material. The third group comprises extremely tough materials (such as nickel-iron and nickel-copper alloys) which have the valuable property of flowing locally at the bottom of the notch even under high deformation speeds.

Experimental Results

Behaviour of structural materials under static and dynamic strain: specimens of various gauge lengths. A series of preliminary tests were performed on specimens of 0.2 in. diameter. Typical stress-strain records obtained with specimens of various gauge lengths (2 in., 1 in., $\frac{1}{2}$ in., $\frac{1}{4}$ in., $\frac{1}{8}$ in., $\frac{1}{16}$ in. and $\frac{1}{32}$ in.) under static tension are reproduced in Fig. 19. These static curves were obtained with a rate of straining of about 0.005 ft. per second. The dynamic tests on specimens having the same gauge length were performed with a rate of straining of 11.78 ft. per second. This means a straining which is about 20,000 times faster than that of the static tests. The energy absorbed dynamically was measured on a standard pendulum impact machine of 60 ft.-lbs. (Olsen) having a maximum speed of 11.78.

The results of the static tests show very clearly the notching effect characterised by a higher load and a lower elongation of most materials, as illustrated in Figs. 9 and 9A. With brass, for instance, the load, from 1,892 lbs. for a 2 in. gauge length cylindrical specimen, increases to 2,725 lbs. for a specimen of the same diameter but having a gauge length of $\frac{1}{32}$ in., representing a strength ratio of 1.43. With aluminium the load increases from 728 lbs. to 1,130 lbs. (ratio 1.55), with mild steel from 3,000 to 5,550 (ratio 1.85), with medium steel from 3,180 to 5,450 (ratio 1.72) and with Monel metal from 3,700 to 6,620 lbs. (ratio 1.79).

The total energy as well as the energy per unit volume, in function of the gauge length of the specimen, for dynamic loading in comparison with static loading are given in Figs. 10 to 14 for the same materials. The ultimate load as well as the elongation under impact and static loads are also shown in these diagrams. It can be seen that for nearly all materials, the total absorbed dynamic energy is always higher than the static, and both the static and dynamic energy decrease rapidly with decreasing gauge length of the specimen. In spite of the very small total energy necessary to fracture notched specimens, the energy per unit volume in both cases of dynamic and static loading, increases with decreasing gauge length. In both cases also, the elongation increases very rapidly. The results of tests in this series on specimens of $\frac{1}{16}$ in. and $\frac{1}{32}$ in. gauge lengths are somewhat irregular.

In Fig. 15, the results are arranged in statistical form in order to provide a comparison between the static and dynamic energy per unit volume necessary to break these specimens: Monel metal, mild steel and medium steel show the highest static and dynamic energy per unit volume. Compared with brass and aluminium these values are, for notched specimens, about seven to ten times higher and show a maximum of 27,900 ft.-lbs. compared to 3,500 ft.-lbs. for brass and 2,000 ft.-lbs. for aluminium.

These results show that the allowable working stresses, expressed in lb./sq. in. and used to calculate the net section of structural members, are not very reliable as

* Continued from page 286, September issue.

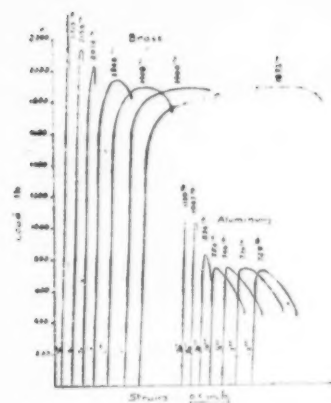


Fig. 9.—Stress-strain records of brass and aluminium specimens of various gauge lengths.

they depend to a large extent on the shape of the member. With statically loaded specimens, for instance, these values can only be used to calculate cylindrical net sections of a certain minimum length; they do not apply to reduced sections, having the shape of a "V" or "U" notch. The allowable stresses become, in this case, appreciably higher and are not related to those of the cylindrical specimens.

On the other hand, with dynamically loaded specimens, these values are of no use, as they have nothing to do with the real impact loads which these materials can support without damage. It would seem that the strength per unit working volume of the elements to be designed, gives much more reliable values for the various structural materials than the strength calculated per unit section. It is the volume of the element that absorbs the applied load and not the section, so that the introduction of the concept of strength per cubic inch into static as well as into impact testing, may give the designer greater security in the selection of structural materials. For instance, a material whose physical properties such as strength per square inch and ductility values are known cannot be used successfully for notched elements which are statically loaded nor for cylindrical and notched elements which are statically

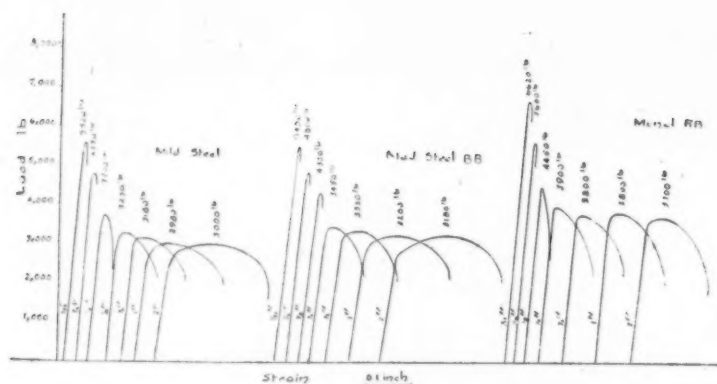


Fig. 9a.—Stress-strain records of mild steel, medium steel and Monel metal specimens of various gauge lengths.

and dynamically loaded. It will be necessary to consider the selection of materials more from the view point of the possibility of maximum energy absorbed per unit volume than from the point of view of their strength per square inch.

B.—Main Tests

(a) *Unpublished results of a previous investigation.*—Before discussing the results of the main series of tests performed on the newly developed device shown in Fig. 1, reference will be made to a few previous results obtained with a similar apparatus.* These dynamic tests were carried out with speeds of 3.4 m. per second and 4.8 m. per second and were compared to static tests recorded with the same apparatus. As shown in Table III, the following differences between static and dynamic loads were revealed: mild steel, for instance, having a static maximum strength of 45 Kg. per square mm. for cylindrical specimens of 50 mm. gauge length has a dynamic strength of 55 Kg. per square mm. at a speed of 3.4 m. per second and 66 Kg. per square mm.

* This device was built and used for recording simultaneously stress-strain curves in dynamic tests performed in 1938-39 at the Warsaw Institute of Metallurgy and Metallography. Because of the political events of September, 1939, the results obtained with this device could not be published and are available only in a short manuscript containing a few characteristic results of this previous investigation with dynamic tests.

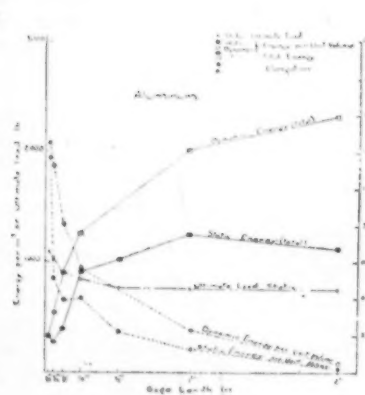


Fig. 10.—Static and dynamic characteristics of aluminium in function of the gauge length.

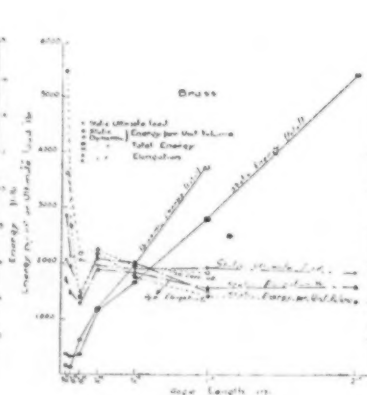


Fig. 11.—Static and dynamic characteristics of brass in function of the gauge length.

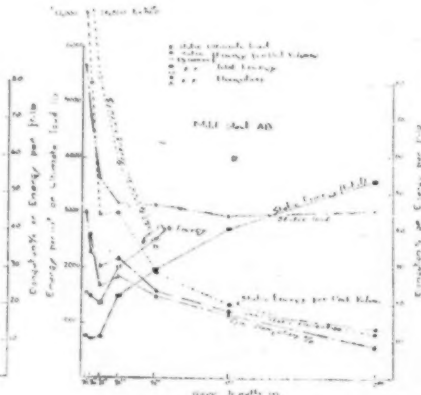


Fig. 12.—Static and dynamic characteristics of mild steel AB in function of the gauge length.

at 4.8 m. per second. The elongation also increases for dynamic loading, the increase varying from 36-47%. With a "V" notch of very large angle, the static strength increases to 50 Kg. per square mm. and the dynamic strength to 69 Kg. per square mm. A sharp rectangular "U" notch increases the static strength further up to 73.5 Kg. per square mm., while a dynamic strength, as high as 109 Kg. per square mm., was measured; this means more than twice the strength of a cylindrical standard specimen under static loads.

Duralumin shows a slight increase between static and dynamic loading of cylindrical specimens (from 44 Kg. per square mm. to 49 Kg. per square mm. for a speed of 4.8 m. per second). A "V" notch of great angle gives a somewhat higher static stress (47 Kg. per square mm.); under a dynamic speed of 3.4 m. per second the load increases to 52 Kg. per square mm., but seems to decrease with higher speeds: at a speed of 4.8 m. per second, a strength of only 43 Kg. per square mm. was measured. For sharp notched specimens, this effect is even much more pronounced, as they showed a decrease in strength ranging from 25-45% at the highest test speed of 4.8 m. per second.

With brass of 49 Kg. per square mm. static strength, a higher strength of 66.6 Kg. per square mm. was found under dynamic loading. However, as with duralumin, a sharp notched specimen showed, at the high-speed impact load, a resistance which was about 40% smaller than that of the dynamically loaded cylindrical specimen.

But with brittle grey cast iron, a much greater effect was measured. The cylindrical specimen under static load had a maximum resistance of 26 Kg. per square mm. At high-testing speeds, this resistance fell down to as little as 2.2 Kg. per square mm. Contrasting with the behaviour of wrought materials, a sharp notch did not increase the breaking strength of grey cast iron. The static strength of the notched specimen was somewhat

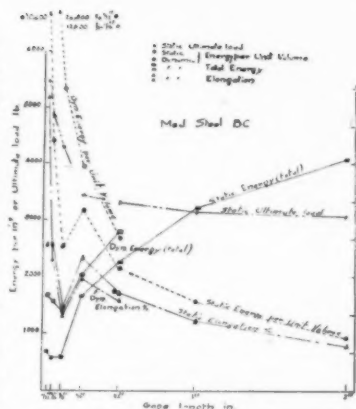


Fig. 13.—Static and dynamic characteristics of medium steel BC in function of the gauge length.

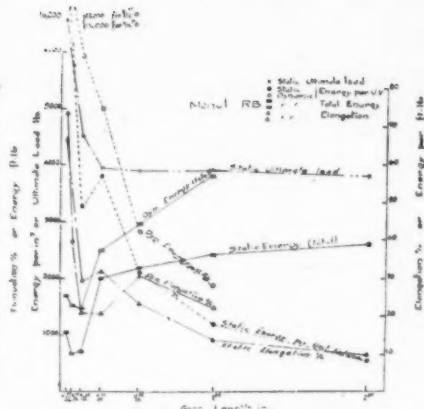


Fig. 14.—Static and dynamic characteristics of Monel RB in function of the gauge length.

smaller (24.5 Kg. per square mm.), but under dynamic load, the strength of this material was decreased appreciably. A loss of about 95% as compared with the static tests was measured, as the strength of the notched specimen under dynamic loads of 4.8 m. per second fell down to as little as 1.5 Kg. per square mm. and that for the "V" notch was 1.1 Kg./mm.² only.

(b) Results of preliminary tests on cylindrical specimens with load-deformation diagrams recorded under static and dynamic tension.

1. Influence of speed on test results with cylindrical specimens of 2 in. gauge length (0, 11.79, 16.68 and 29 ft./sec.).—The results of tests on cylindrical specimens of 2 in. gauge length and diameters of 0.175-0.2 in., varying with the ultimate load of the material tested, are given in Fig. 16. Besides the tests with speeds of practically 0 ft./sec., tests were also carried out where the impact loads were applied with three different speeds: 11.78 ft./sec., 16.68 ft./sec., both performed on the Riehle impact machine; and at 29 ft./sec., performed on the newly designed impact machine of Ecole Polytechnique. It can be seen from these results, graphically shown in Fig. 16, that the strength of all materials tested increases markedly with gradual increase of the speed of loading. Thus, for instance, the ultimate

TABLE III.
UNPUBLISHED TEST RESULTS OF STATIC AND DYNAMIC TENSION TESTS WITH STRESS-STRAIN RECORDS.

Material	Specimen	Ultimate Strength Kg./mm. ²					
		Static	Strength ratio notched stand	Dynamic			
				Speed			
				3.4 m./sec.	Speed ratio dynamic static	4.8 m./sec.	Speed ratio dynamic static
Mild steel	Cylindrical 4 in. gauge length	45	—	55	1.22	66 ¹	1.47
Mild steel	V notch 160°	50	1.25	—	—	69	1.38
Mild steel	U notch	73.5	1.63	—	—	109	1.47
Duralumin	Cylindrical	44	—	—	—	49	1.11
Duralumin	V notch	47	1.07	52	1.1	43 ²	0.91
Duralumin	U notch	—	—	—	—	increasing 25-45	—
Brass	Cylindrical	49	—	—	—	66.6	1.34
Brass	U notch	—	—	—	—	decreasing of max: 40%	—
Copper cold drawn	Cylindrical	—	—	—	—	increasing	—
Copper cold drawn	U notch	—	—	—	—	substantially smaller	—
Zinc	Cylindrical	9.5	—	11.2	1.17	2.1 ³	0.22
Zinc	U notch	12.9	1.35	increasing	—	1.6	0.12
Cast iron	Cylindrical	26	—	—	—	2.2	0.08
Cast iron	V notch	24.5	0.94	30	1.22	1.5	0.06
Cast iron	U notch	26	1.0	28.8	1.11	1.1	0.04

¹ Elongation static test, 36%. Elongation dynamic test, 17%. Reduction of area practically unchanged.

² Energy absorbed dynamically greater than statically.

³ Elongation substantially smaller than for statically tested specimens.

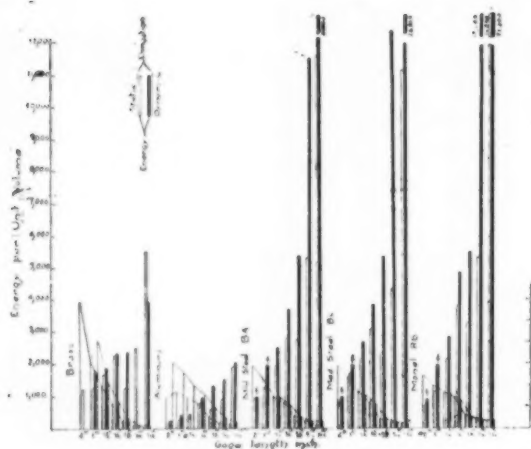


Fig. 15.—Statistical survey of static and dynamic properties of various structural materials in function of the gauge length.

strength of duralumin is about 33% higher at a speed of 11.78 ft./sec. than in the static test; brass, aluminium and magnesium alloys show an increase of 38–58%, and the dynamic ultimate strength of zinc is even 100% higher than its static ultimate strength.

With greater loading speeds of 16.68 ft./sec. and 29 ft./sec. the ultimate strength still increases, and brass as well as duralumin shows an increase of 76–92% over the static strength. Zinc, however, after an increase of 147% for the intermediate speed has, at 29 ft./sec., a strength lower than at a speed of 16.68 ft./sec.; the increase over the static strength is only 119% at the high velocity. The results of these preliminary tests are in fair accordance with the author's previous investigation carried in collaboration with S. Morski and whose results were published.¹² From these results, it was stated that "for all the materials, the tensile strength of specimens, strained at 1 m./sec. is 12–39% greater than in the static test. With specimens strained between 1 and 4 m./sec. the increase is less pronounced but at higher

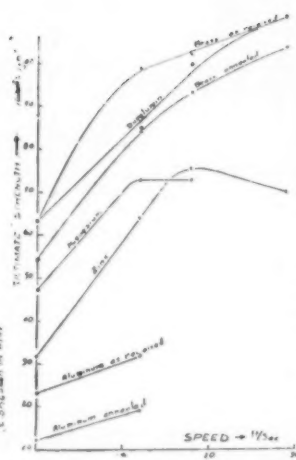


Fig. 16.—Influence of loading speed on the ultimate strength of 2 in. gauge length cylindrical specimens.

rates some of the materials show again a marked increasing strength. With zinc, there is an increase in strength of 33% at 1 m./sec., but at higher rates the strength decreases again, without, however, reaching the value obtained in the static test."

Moreover, the influence of the deformation speed on the elongation of these materials is very pronounced. It can be seen from Fig. 17 that all materials tested show an increase in elongation with higher speeds from about 13% to over 100%, except zinc showing a decrease of about 44% for a deformation speed of 29 ft./sec. These results are also in conformity with the results of the above-mentioned investigation where it was

stated that: "for most of the materials tested, the elongation increases, as the rate of straining increases. Zinc behaves quite differently from all the other materials since its elongation at first decreases sharply (by about 53%) and then more slowly with increasing rates of straining."

The reduction of area was also measured, and it appears that this value increases slightly or remains practically unchanged with higher deformation speeds. Again, zinc behaved differently, showing a smaller reduction of area at high speeds.

(c) Results of tests with load-deformation diagrams on notched specimens under static and dynamic loads; the influence of speed on test results of specimens of various gauge lengths.

As a result of the experience gained in earlier tests, these series of tests were carried out with specimens where the shape of the gauge length was varied, changing the angle of the notch. The dimensions of all the specimens used are given in Fig. 8 for the first series of tests on cylindrical and notched specimens; one specimen had a 2-in. gauge length, one had "V" notches of either 160° angle or 120°, one of 90° and one with a very sharp U notch.

1. Results for soft metals.—Having regard to the dynamic recording device, which at the beginning of this investigation was designed for a maximum load of about 1,500 lb.

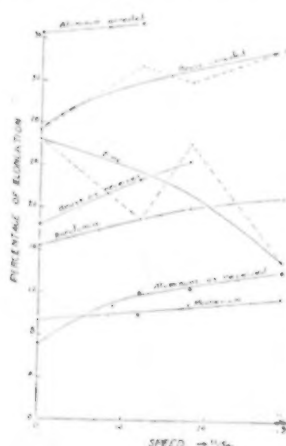


Fig. 17.—Influence of loading speed on the elongation of 2 in. gauge length cylindrical specimens.

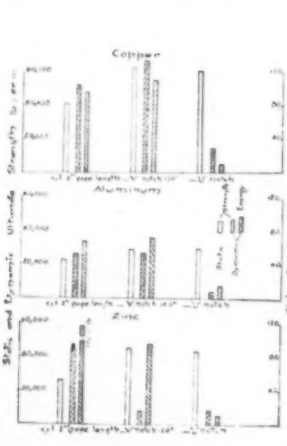


Fig. 18.—Test results of cylindrical and notched specimens under static and dynamic loads (speed 11.79 ft./sec.)

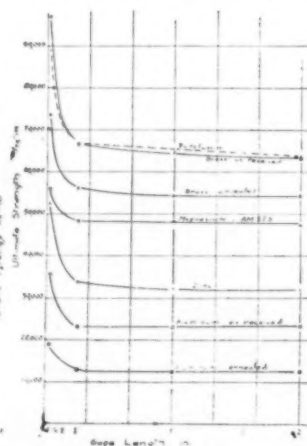


Fig. 20.—Influence of gauge length of specimens on the ultimate strength of various materials tested under static loads.

¹² G. Welter and S. Morski, *Journal Inst. Metals*, London, Vol. 66, Pt. 4, pp. 97–107, 1940.

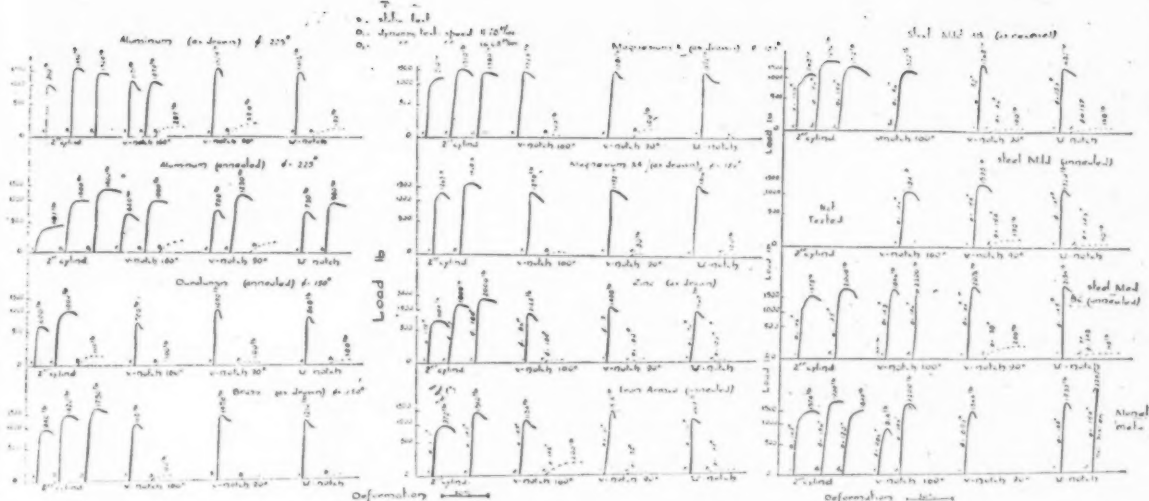


Fig. 19.—Records of static and dynamic tests on cylindrical and notched specimens of various structural materials (speed 11.79 and 16.68 ft./sec.)

only, the first test series was run with specimens of soft metals and alloys such as copper aluminium and zinc, having a gauge length diameter of 0.185 in. for copper and 0.225 in. for zinc and aluminium.

The static and dynamic results are given in Fig. 18; the speed for the dynamic test was 11.78 ft./sec.

These results already give interesting information on the behaviour of cylindrical and notched specimens under static and dynamic tensile loads. On one hand, the static strength increases very rapidly with increasing sharpness of the notch; copper for instance, showing an ultimate strength of 41,450 lb./sq. in. for a cylindrical 2-in. specimen, shows an increase in strength up to 60,800 lb./sq. in. for a sharp U-notched specimen. Furthermore, the cylindrical specimen withstands higher dynamic loads than static loads; thus, for instance, 52,100 lb./sq. in. were reached. The total energy

absorbed by the apparatus during dynamic fracture was of about 97 ft./lb. of this specimen. For a specimen with a V notch the maximum load was 67,000 lb./sq. in. and the energy 110 ft.-lb. With sharp U-notched specimens, the dynamic strength is extremely low compared to the dynamic strength of other shapes of specimens; even very ductile materials, such as copper tested in this shape behave like brittle material under impact loads. The automatically recorded load-deformation diagram indicates an ultimate strength of only 13,000 to 15,000 lb./sq. in. and the total energy necessary to break the notched copper specimen is only 10-11 ft.-lb. This is in contrast with the results of static tests where the sharp U-notched specimen showed a higher tensile strength than the cylindrical one.

To be continued.

New High Vacuum Equipment Venture

NATIONAL RESEARCH CORPORATION, Cambridge, Massachusetts, announces the formation of British American Research Limited which has recently been incorporated in Scotland as a joint venture with Daniel Varney Limited. Daniel Varney, Limited, controlled by Sir James Lithgow, Scottish Industrialist and Shipbuilder, during the war has been engaged in the manufacture of scientific research instruments and laboratory apparatus.

British American Research Limited will undertake the manufacture and sale of the industrial high vacuum equipment which has been developed by the National Research Corporation and widely used throughout the world in such fields as high vacuum evaporation, distillation, dehydration and metallurgy.

According to Richard S. Morse, President of National Research Corporation, this new British Company will not only facilitate the availability of high vacuum equipment particularly to the British Empire, but, in addition, its rapidly expanding staff will serve in a liaison capacity for the latest technical developments coming from the United Kingdom and the Continent.

The officers of the British American Research Limited

include Mr. Norman Duthie (chairman), Senior Partner of Mann, Judd, Gordon and Co., Chartered Accountants, Glasgow; Dr. Charles G. Hatay (managing director). In addition to Mr. Duthie and Dr. Hatay, the directors include Richard S. Morse and the Earl of Selkirk.

Fuel Automatic Control Technique

THERMOSTATIC control is the major fuel-saving aspect of the technique of fuel automatic control. It can be applied to a multiplicity of operations in the space heating of factories and to industrial processes. The saving is effected automatically and maintenance troubles are negligible. Much information on this subject is given in an attractive booklet, which has been prepared by the Fuel Efficiency Committee in collaboration with a panel of experts drawn from manufacturers and installation contractors of thermostatic control equipment. The booklet is profusely illustrated and a copy may be obtained free from the Ministry of Fuel and Power, Queen Anne's Chambers, Dean Farrar Street, London, S.W.1, or from the Ministry's Regional offices.

Forthcoming Meetings

Institution of Mechanical Engineers. Discussion on the "Manufacture of Turbine Blades" for the Whittle Engine, by T. A. Kestell, A.M.I.Mech.E., on October 31, at 5-30 p.m. "Independent Suspension Systems," by M. A. Jullien, on November 4, at 6 p.m. Discussion on the Measurement of the Temperature of "Sliding Surfaces," with particular reference to Railway Brake Blocks, by R. C. Parker, Ph.D., B.Sc., and P. R. Marshall, Ph.D., B.Sc., on November 7, at 5-30 p.m.

Institution of Engineers and Shipbuilders in Scotland. "Steel Processing," by Mr. J. A. Kilby and Mr. W. G. Cameron on November 4.

Iron and Steel Institute. Autumn Meeting on November 12-13, at the Institution of Civil Engineers, Great George Street, S.W.1, and at 4, Grosvenor Gardens, S.W.1.

West of Scotland Iron and Steel Institute. "The Selection and Use of Steel for Steam Turbines," by Dr. C. Sykes, F.R.S., on November 21, at 6-45 p.m., at 39, Elmbank Crescent, Glasgow.

Institute of Metals. *Birmingham Section:* Open Discussion—"The Significance of Mechanical Testing," on October 23; "The Determination of Constitutional Diagrams," by Dr. G. V. Raynor, M.A., on November 6. *London Section:* "Some Aspects of Metal Refining," by Prof. C. W. Dannatt, A.R.S.M., D.I.C. on November 13. *Scottish Section:* "Commentary on a Visit to America," by Mr. A. Craig MacDonald, B.Sc., on November 10. *Sheffield Section:* "Electroplating Problems," by Mr. A. W. Hothersall, M.Sc., on October 31. *Swansea Section:* "The Place of the Metallurgist in Industry," by Sir Arthur Smout, on November 19.

Institute of Welding. Presidential Address by Mr. J. L. Adam, C.B.E., on October 29 at 6 p.m., at the Institution of Civil Engineers, Great George Street, S.W.1.

Institute of Marine Engineers. *Junior Section:* "Photo-Elasticity," by Dr. J. Ward on November 6 at 4-45 p.m., at the City and Guilds College, London, S.W.7; "Modern Alloy Steels," by Mr. T. E. Alker, A.M.C.T., A.I.M., on November 12, at 7-15 p.m., at the Technical College, Cardiff; "Precision Measurement," by Mr. W. O. Jennings, B.Sc., on November 18, at 7-15 p.m., at Wimbledon Technical College, London, S.W.19.

Sheffield Metallurgical Association. "The Manufacturer of Sponge Iron," by Mr. Eketorp of Uddeholm Steel Co., Sweden, on October 21, at 7 p.m.; Joint Meeting with the Royal Institute of Chemistry, Chemical Metallurgy, by Dr. H. J. T. Ellingham, on October 24, at 7 p.m.; "Photo-Elasticity Applied to Design Problems," by Mr. R. B. Heywood, on October 28, at 7 p.m.; Joint Meeting with the Iron and Steel Institute at which the following papers will be discussed: "Hydrogen in Steel Manufacture," by Dr. C. Sykes, F.R.S., Mr. H. H. Burton, and Mr. C. C. Gegg, and "Hydrogen and Transformation Characteristics in Steel," by Prof. J. H. Andrew, Mr. H. Lee, Mr. H. K. Lloyd and Mr. N. Stephenson, on November 4, at 7 p.m.; "The Metallurgy of Musical Instruments," by Mr. J. C. Williamson, on November 11, at 7 p.m. These Meetings will be held at 198, West Street, Sheffield, 1.

Institute of British Foundrymen. *Middlesbrough Branch:* "The Application of Hydro-Blast to Cleaning

Castings and Sand Recovery," by Mr. W. Y. Buchanan, on November 14, at 7 p.m. *East Midlands Branch:* "Foundry Problems," papers submitted by members on October 25. *London Branch:* "The Production of Cast Crankshafts," by Mr. R. B. Templeton, on October 29. *Falkirk Section:* "The Protection of Metals Against Corrosion," by Mr. W. Westwood, B.Sc., on October 31. *Lancashire Branch:* "The Influence of Production Flow on Moulding Methods in Iron Foundries and its effect on P.M.H. and General Efficiency," by Mr. R. C. Shepperd. *West Riding of Yorkshire Branch:* Visit to Hadfield's Ltd., followed by the display of a film on the Production of High Quality Steel, on November 8. *Newcastle Branch:* "The Scientist in the Foundry," by Mr. C. R. Tottle, B. Met., on November 8. *East Anglian Section:* Symposium on "Special Patterns," contributed by local foundries, on November 9. *Sheffield Branch:* "The Surface Drying of Moulds," by Mr. F. Cousins, on November 10. *Slough Section:* "Precision Castings for General Engineering Purposes," by Mr. F. Hudson, on November 11. *Lincoln Section:* "The Metallurgist in the Foundry," by Mr. W. H. Salmon, F.I.M., on November 13.

Manchester Metallurgical Society. "Electrical Strain Gauges," by Mr. E. Jones, M.Sc., on November 5, at 6-30 p.m., in Engineers' Club, Albert Square, Manchester.

Royal Aeronautical Society. "The Problem of High Temperature Alloys for Gas Turbines," by Sir William T. Griffiths, D.Sc., F.R.I.C., F.Inst.P., F.I.M., on October 23, at 6 p.m. The Third British Commonwealth and Empire Lecture will be delivered by Mr. James Bain of Trans-Canada Airlines on October 30, at 6 p.m. These lectures will be held at the Institution of Civil Engineers, Great George Street, S.W.1.

Machine Tool and Engineering Exhibition, London, 1948

THE 1948 Exhibition will open at Olympia on the 26th August, 1948, and close on the 11th September, 1948. It will be the largest show of machine tools, woodworking machine equipment and accessories ever staged in Great Britain. The three halls at Olympia have been taken and there will be nearly a quarter of a million square feet of Exhibition.

Zirconal Ltd.

ZIRCONAL LTD. has been formed in conjunction with Silicon (Organic) Developments Ltd., 11, Cavendish Place, London, W.1, as a production unit for the manufacture of Synthetic "Mullite" and "Zircon" refractory compounds, using the Sil ester bonding process. They are fully equipped to make semi-permanent moulds and dies, crucibles, furnace equipment, electrical and other components where thermal and electrical resistance, together with strength and refractoriness, are required.

The Aluminium Development Association has issued a new publication under the title *The Aluminium Courier*, which will appear approximately quarterly. It is primarily for users and potential users of aluminium and its alloys and is designed to give useful technical and non-technical information on the subject. The first issue is concerned with structural engineering and copies may be obtained on application to the Aluminium Development Association, 33, Grosvenor Street, London, W.1.

Investigations on Colorimetric Methods of Metallurgical Analysis

Part III—Permanent Standards for the Colorimetric Determination of Molybdenum in Alloy Steels

By G. V. L. N. Murty, M.Sc., A.R.I.C., D.Sc.

It has been shown that the stability of the colour involved in the visual colorimetric estimation of molybdenum in alloy steels could not be increased beyond eight hours by effecting modifications in the procedure or addition of perchloric acid. The attempts made to explore possibilities of preparing duplicates of these colours by suitably mixing solutions of judiciously selected inorganic substances have been described. It is shown that satisfactory duplicates which cover the entire range in view and remain stable for more than a month may be prepared by employing mixtures of potassium dichromate and cobalt nitrate solutions.

IN most visual colorimetric methods the colours are simultaneously developed for the standards and the test solutions as they are not generally stable for a long time. This disadvantage is indeed more pronounced in the tropics where the abundance of light and the prevailing high temperatures render the colours less stable. Having permanent colour standards with which the test solutions could be readily compared would be a very desirable simplification, though not always a feasible proposition. An investigation has, therefore, been undertaken to explore the possibilities of preparing permanent colour standards in connection with the procedure recently worked out for the visual colorimetric estimation of molybdenum in alloy steels (Part II of this series).¹ It may be recalled in this connection that the final colour involved in the method is not stable for more than four hours.

In the investigations described in this paper the stability of the colour has been judged by the constancy of the drum differences in the Spekker photo-electric absorptiometer. Attempts to increase the stability by effecting alterations in the concentrations of the reagents did not meet with any appreciable degree of success. The next attempt was to keep the coloured solutions in a bath of cold water (15° C.) and protect them from the action of light. This precaution indicated some improvement, but it was only possible to increase the stability up to eight hours. Table I embodies the results obtained.

TABLE I.

% Mo	Drum differences at the time intervals noted (precaution not observed)				Drum differences at the time intervals noted (precaution observed)			
	2 Hrs.	4 Hrs.	8 Hrs.	10 Hrs.	2 Hrs.	4 Hrs.	8 Hrs.	10 Hrs.
0.30	18.5	18.5	16	14	18.5	18.5	18.0	16
0.40	25.0	25.0	22.5	20	25.0	25.0	25.0	22
0.50	31.0	31.0	28.5	26	31.0	31.0	31.0	29

It is indicated in recent literature² that the addition of perchloric acid increases the stability of the colour. A series of experiments have, therefore, been performed by adding 4 ml. of 60% perchloric acid before the addi-

tion of the mixed reagent. In addition, the above-mentioned precautions were also observed. The colours were found to fade after eight hours though the rate of fading was lower when perchloric acid was employed. The results are recorded in Table II.

TABLE II.

% Mo	Drum differences at the time intervals noted									
	Without perchloric acid					With perchloric acid				
	2 Hrs.	4 Hrs.	8 Hrs.	10 Hrs.	16 Hrs.	2 Hrs.	4 Hrs.	8 Hrs.	10 Hrs.	16 Hrs.
0.30	18.0	18.0	18.0	16.0	9.0	18.0	18.0	18.0	17.0	12.0
0.40	24.5	24.5	24.5	22.0	15.0	24.5	24.5	24.5	23.0	18.0
0.50	30.5	30.5	30.5	28.0	21.0	30.5	30.5	30.5	28.5	24.0

It is obvious from the results presented in Table I and II that the stability could not be increased beyond eight hours. The next attempt has, therefore, been to see if the colours could be successfully duplicated by a suitable choice of solutions of stable inorganic substances. The findings are described in the following section. In all the cases preliminary visual adjustments were finally checked by means of Spekker photo-electric absorptiometer.

(i) Chromic Acid Solutions

By suitably diluting chromic acid solution it has been possible to duplicate the colours corresponding to 0.5 and 0.6% Mo, but not the lower ranges of concentration. This seems to be due to the well-known fact that in dilute solutions chromic acid acquires more yellowish tints.

(ii) Potassium Dichromate and Potassium Permanganate Mixtures

By carefully adding small quantities of a very dilute solution of permanganate to dilute solutions of potassium dichromate it was possible to duplicate the colours corresponding to 0.3–0.6% Mo. These duplicated colours were quite stable for about four days after which the permanganate was found to be reduced. On using the water redistilled over permanganate for preparing the solutions the stability could be increased up to seven days. The results obtained are presented in Table III.

¹ Murty, Proc. Ind. Sc. Cong. 1946, *Metallurgia*, 1947, 35, 167.

² Haywood and Wood, "Metallurgical Analysis by Means of Spekker Absorptiometer," (Hilger publication), 1944, p. 57.

TABLE III.

Drum differences are given						
% Mo	Solution by the usual method	Duplicates on the same day	Duplicates 4th day	Duplicates 7th day—ordinary distilled water used	Duplicates 7th day—re-distilled water employed	Duplicates 10th day—re-distilled water employed
0.30	18.5	18.0	18.0	15.0	18.0	16.0
0.40	25.0	25.0	25.0	21.0	25.0	22.0
0.50	31.0	31.5	31.5	28.0	31.0	27.0
0.60	37.0	37.0	36.5	31.0	37.0	32.0

(iii) Potassium Dichromate and Cobalt Nitrate Mixtures

Duplicates prepared with these mixtures proved to be most satisfactory. Colours had been duplicated corresponding to 0.05–0.60% Mo, and were found to be stable for about a month. Even after a month the solutions corresponding to more than 0.3% Mo were found to be quite satisfactory. The results obtained are given in table IV.

TABLE IV.

Drum differences are given					
% Mo	Solution by the usual method	Duplicates on the same day	Duplicates after 1 month	Duplicates after 1½ months	Duplicates after 3 months
0.05	4	4	4	—	—
0.10	6	6	6	2	—
0.20	12	12	12	6	6
0.30	18.5	18.5	18.5	17.5	17
0.40	25.0	25.0	25.0	25.0	24.5
0.50	31.0	31.0	31.0	31.0	30.0
0.60	37.0	37.0	37.0	37.0	36.0

It is readily seen from the above table that the duplicates prepared by judiciously mixing potassium dichromate and cobalt nitrate are highly satisfactory for use as standards. The use of these semipermanent standards effects a further simplification in the new procedure for the visual colorimetric estimation of molybdenum in alloy steels.

The author's thanks are due to the management of the Tata Iron and Steel Co., Ltd., for permitting the publication of this paper and to Mr. N. B. Sen, Chief Chemist, T.I. and S. Co., Ltd., for his keen interest in the work.

The Use of Starch in the Titration of Fluoride with Thorium Nitrate in the Presence of Alizarin Red S

By W. Stross

In the titration of the fluoride ion with thorium nitrate on the macro scale the precipitation of thorium fluoride makes the detection of the endpoint very difficult; by adding starch solution the formation of this precipitate is prevented and the detection of the endpoint greatly facilitated.

IN the original paper¹ introducing the use of sodium alizarin sulphate (alizarin red S) as indicator for the Willard-Winter² titration of fluorides with thorium nitrate it was pointed out that the procedure "succeeds best with fractional quantities of a milligram of fluorine since the troublesome absorption of the dye and the lake on the precipitated thorium fluoride is rendered less noticeable."

In assaying fluorspar and similar materials it is, however, often undesirable—particularly in routine laboratories—to work with such small quantities and as a matter of fact the method has been recommended on a macro scale comparatively recently³ for the analysis of fluorspar, using a steam distillation. A 200 mg. sample is taken for the distillation and four-tenths of this are finally titrated, thus up to approximately 40 mg. of fluorine.

In applying this procedure over a period of several years in these laboratories it was found that good results could be obtained, but only after considerable practice was the colour change seen with any degree of precision. The use of a "comparison sample" was not particularly helpful, as the amount of thorium fluoride would have to be very similar and the comparison flask would have to be swirled together with the one containing the sample under test, to provide a similar optical impression; the

colour also changes with the ageing of the precipitate, which further complicates the conditions.

The use of a protective colloid to prevent the formation of a precipitate was the obvious answer and after experiments with various colloids—e.g., gelatine and gum arabic—it was found best to add 10 ml. of a 5% starch solution to 100 ml. of the distillate.

Under these conditions the colour change is sharply defined and can be recognised easily and without practice; the use of the little dodge recommended for difficult titrations⁴ is hardly necessary.

The starch solution is prepared as follows: Bring 80 ml. of water to the boil in a conical flask. Suspend 5 g. of soluble Lintner starch (Hopkin and Williams) in 20 ml. cold water, by stirring, and pour this slowly, whilst stirring the suspension, into the boiling water. Use some of the boiling solution to transfer the rest of the starch into the bulk of the solution, boil for 2 mins. and pour the hot solution on a Whatman 541 filter (15 cm. diameter). Do no wash. Cool the filtrate.

It would be an advantage to have a stable starch solution available and a solution stabilised by preparing it with saturated sodium or potassium chloride solution in lieu of water⁵ was tried. The colour change was, however, not so well defined, probably due to the high chloride content; sodium sulphate solution (saturated

¹ Armstrong, W. D. *J. Ind. and Proc. Amer. Chem. Soc.*, **55**, 1933, 1741.

² Willard, H. H. and Winter, O. R. *Ind. Eng. Chem. (Anal.)*, **5**, 1933, 7.

³ Frayser, G. L. *Deco Trefoil*, **7**, 1943, 2, p. 5; *The Chemical Age*, 1943, 613.

⁴ Schuelek. *Zsche. Anal. Ch.*, **127**, 1944, 196.

⁵ Ivar Bang. *Mikromethoden zur Blutuntersuchung*, 6th edition, Munich, 1927, p. 23.

and half saturated) was also tried, but does not produce a stable starch solution.

After these experiments were completed a recently published short general hint at the use of a protective colloid for the same purpose⁶—although in combination with a different indicator—came to the writer's notice:

⁶ Milton, R. F., Liddell, H. F., Chivers, J. E. *The Analyst*, **72**, 1947, 43.

it is, however, thought that the publication of the detailed prescription may nevertheless be useful for the metallurgical routine laboratory.

These experiments were carried out in the laboratories of Messrs. International Alloys, Ltd. in Aylesbury and, the author wishes to thank the directors of this company for permission to publish.

The Determination of Zinc in Metallic Cobalt by Dithizone

By R. S. Young, Ph.D., F.R.I.C.

(Central Laboratory, Rhokana Corporation, Ltd., Nkana, Northern Rhodesia)

A dithizone procedure is described for the determination of small quantities of zinc in metallic cobalt and similar refined metals. The method is simple, rapid and accurate and offers some advantages over conventional methods when small quantities are involved.

THE determination of small quantities of zinc in refined metals containing a number of other impurities is usually a lengthy and troublesome procedure. Metallic cobalt produced from certain localities, notably the Belgian Congo, may contain in the neighbourhood of 0.01–0.02% zinc, together with the accompanying impurities, in approximate percentages: Cu 0.02, Pb 0.02, Ni 0.6, Mn 0.02, Ag 0.01, and smaller quantities of As, Sb, Bi, C, SiO₂, Fe, S, etc. The procedure described below was developed for this type of material, but has obvious applications for small quantities of zinc in other refined metals.

Dithizone has been used in recent years for the determination of small quantities of a number of metals. Most of these procedures, together with the theory underlying dithizone separations, are reviewed in Sandell's monograph.¹ In a weakly acid medium the green dithizone solution in carbon tetrachloride reacts quantitatively with zinc to give a red solution of zinc dithizonate. Unfortunately, many other metals also react with dithizone under these conditions, so that it is necessary to form complexes with them to prevent interference in the zinc determination. Potassium cyanide forms complexes with cobalt and nickel, while sodium thiosulphate is employed to inhibit reaction of dithizone with bismuth, cadmium, copper, gold, lead and mercury.

Procedure

Decompose a 5-gram sample of metallic cobalt in HNO₃ or aqua regia, cool, and make up to 1 litre in a volumetric flask. Withdraw a 10 ml. aliquot for analysis, equivalent to 0.05 gm. sample containing in the neighbourhood of 0.00001 gm. or 10 γ zinc. Place the 10 ml. aliquot in a 60 ml. separatory funnel, add 10 ml. of 5% potassium cyanide, a few drops of B.T.L. universal indicator, and slightly acidify with dilute HCl. Adjust the pH of the solution to 4.5–5.5 with a few drops of saturated sodium acetate, and add 0.2 ml. of 25% sodium thiosulphate.

Add 1 ml. of standard dithizone solution from a burette, shake the separatory funnel vigorously for 10–15 seconds or until the green solution turns red, showing that the dithizone has reacted completely to form red zinc dithizonate. Draw off the red solution into a test tube. Add successive quantities of the standard dithizone solution, shake, and draw off as before until the lower carbon tetrachloride layer no longer

turns red or brown but remains green after shaking, indicating that all the zinc has reacted with the dithizone. Transfer the zinc dithizonates to a test tube. It is not necessary to record the volume of standard dithizone used at this stage since the zinc must be shaken out with dilute acid and re-titrated.

Transfer the combined dithizonates of zinc and traces of other metals from a test tube back to the separatory funnel and add 10 ml. of 0.02 N HCl. Shake vigorously to transfer zinc to the aqueous phase. Run the two phases into separate test tubes, return the CCl₄ phase to the separatory funnel and shake vigorously again with 10 ml. of 0.02 N HCl. Discard the lower CCl₄ layer and combine the two aqueous phases containing zinc. Adjust the pH of the zinc solution to 4.5–5.5 with saturated sodium acetate, add 0.2 ml. of 25% sodium thiosulphate, a few drops of 5% KCN solution and 2 ml. of 5% hydroxylamine hydrochloride. If some cobalt is still present a precipitate will be formed initially with KCN, but it disappears when excess cyanide is added. If cobalt is present the addition of cyanide will also complex any nickel; if cobalt is absent the quantity of nickel remaining at this stage is negligible.

Extract the zinc with dithizone by successive additions and withdrawals until the lower CCl₄ layer no longer turns red on shaking but remains green. Since the dithizone is standardized by titrating similar quantities of standard zinc under the same conditions the quantity of dithizone used is an accurate measure of the zinc in the sample.

Though the concentration of zinc dithizonate in the carbon tetrachloride solution may be found by measuring the transmittancy with a green filter or by obtaining the concentration of the remaining dithizone from the measurement of the transmittancy with a red filter, we have found that the simple titrimetric procedure outlined above is very satisfactory for work of this nature.

A solution of dithizone containing 0.2 gm. per litre of carbon tetrachloride is a suitable one, since it has an approximate value of 1 ml. = 2.5 γ zinc. The dithizone solution should be standardized daily against a known zinc solution, and stored in the dark in a large separatory funnel under a layer of sulphurous acid. It is conveniently withdrawn from this funnel to a 10 ml. burette.

Since the presence of traces of zinc is widespread in reagents it is advisable to extract the sodium acetate, sodium thiosulphate, potassium cyanide, etc., with a small quantity of dithizone solution and remove traces

¹ Sandell, E. B. "Colorimetric Determination of Traces of Metals," New York, Interscience Publishers Inc., 1944.

of the latter, if necessary, by a final extraction with CCl_4 . Pyrex glassware must be used throughout, and as in all dithizone procedures the sensitivity of the reaction requires scrupulous cleanliness in rinsing glassware with distilled water, etc.

For those who have not had experience with dithizone methods a few general remarks might be included. Shaking the separatory funnel to bring about rapid reaction of dithizone with traces of metals should be done vigorously with a snap of the wrist. A cord attached to the funnel stopper may be looped over the forefinger, a continuous slight tension on the cord ensuring that the stopper remains in place. After shaking, a slight rotary swirling motion of the solution in the separatory funnel hastens the settling of small droplets of the CCl_4 solution. Careful adjustment of the pH of the solution with dilute HCl and NH_4OH , and the use of a buffer like sodium acetate, are required.

The procedure is simple, reproducible, and the precision is of the order of $\pm 5\%$ in the range of 0.005–0.05% zinc. It is quite rapid and affords a substantial saving of time over conventional procedures, particularly where only a few determinations are required.

The procedure as outlined above can be carried out in the presence of such small quantities of the following metals as may be found in refined metals—i.e., 10–1,000 times the amount of zinc present: Al, Sb, As, Bi, Ca, Cr, Co, Fe, Pb, Mg, Mn, Hg, Mo, Ni, Ag, Sn, Ti, W, U,

V, Zr. For the rare occasion when more cadmium is present than zinc, the former may be largely removed by washing the zinc dithizonate 4–5 times with 5 ml. of 40% sodium sulphide solution, as Cd tends to react with dithizone even in the presence of sodium thio-sulphate.

Reagents

Dithizone. Dissolve 0.2 gm. diphenylthiocarbazon in 1 litre of AnalaR carbon tetrachloride, filter, and store in a cool dark place.

Potassium cyanide. Dissolve 50 gm. AnalaR KCN in water and make up to 1 litre.

Sodium acetate. Dissolve 100 gm. hydrated AnalaR sodium acetate in 100 ml. water.

Sodium thiosulphate. Dissolve 25 gm. AnalaR $\text{Na}_2\text{S}_2\text{O}_3 \cdot 5\text{H}_2\text{O}$ in water and make up to 100 ml.

Zinc solution. Weigh out 0.0062 gm. AnalaR zinc oxide, dissolve in 2–3 ml. HCl and make up to 500 ml. with water. 1 ml. = 0.00001 gm. or 10 γ Zn.

Hydroxylamine hydrochloride. Dissolve 5 gm. AnalaR hydroxylamine hydrochloride in water and make up to 100 ml.

Summary

A dithizone procedure is described for the determination of small quantities of zinc in metallic cobalt and similar refined metals. In the range of 0.005–0.05% Zn it is simple, rapid, and accurate, and offers several advantages over conventional methods for such quantities.

The Geology and Mineral Resources of Palestine

By S. H. Shaw, M.Sc., A.R.S.M.

AN informative lecture was given by Mr. Shaw on the above subject at a recent meeting held at the Imperial Institute, in which he described the physical and climatic characteristics of Palestine, a country about the size of Wales, and said that from the coastline on the west to the line of the River Jordan and Dead Sea on the east there were three distinct zones: first the coastal plain varying from twenty-five miles in width to practically nothing at Haifa; second the hill region forming the backbone of the country; and third, the narrow zone formed by the Dead Sea rift, a unique feature comprising the lowest land surface on the earth.

Structurally, the most striking feature of the country was the Dead Sea trough with its nearly north to south trend and faulted margins but the principal direction of folding, particularly in the south, was along N.N.E. to S.S.W. axes and this had produced a number of asymmetrical anticlines with steeply dipping south-east flanks and gentler north-west ones. North of Jerusalem the parallel trend of the folding was less evident and in Northern Palestine the structures were more complex and consisted largely of much broken fault blocks. Reference was also made to the structural relationship of the Dead Sea rift to the African rift valley systems and to the theories of the origin of these remarkable features.

Palestine was unfortunately not rich in mineral deposits although it was by no means without some useful resources. Fundamentally water was the most vital mineral product and not being rich in surface supplies the country relied to a very great extent on underground supplies. Water was required for domestic

consumption in towns and villages and for irrigation projects, orange growing and other agricultural purposes. The main underground water supplies were found in the coastal plain and were obtained both from the younger sediments and in some parts from the underlying Upper Cretaceous limestones, the water in the latter case usually being under sub-artesian pressure. A very considerable amount of information about these supplies was available and generally speaking the problems involved were those of quantity rather than finding water itself.

The most important source of minerals in Palestine was the Dead Sea from which potash and bromine were extracted in the plants of the Palestine Potash Company at the north and south ends of the sea. Other minerals in production or that had been produced were gypsum, rock salt and sea salt, sulphur, felspar, barytes and limestone and clay for cement production. In addition, the country produced large quantities of limestone for building, lime burning, and roadstone; sand for building and the manufacture of silicate bricks and clay for brick making. Clay had also been used to a limited extent for pottery and basalt for the manufacture of fused products such as insulators and the more weathered varieties for pozzuolana. Some production figures were given

Mineral	1946 Production	Production over a period
Potash 80% KCl	90,571 tons	1935 to 1946 868,226 tons
Bromine	50 "	1935 " 1946 6,222 "
Bromine salts	" "	1941 " 1945 4,400 "
Gypsum	14,512 "	1930 " 1946 85,694 "
Rock salt	1,571 "	1930 " 1946 18,587 "
Sea salt	11,413 "	1936 " 1946 144,707 "
Sulphur	" "	1935 " 1942 8,807 "
Felspar	53 "	1943 " 1946 240 "
Barytes	3 "	1943 " 1946 26 "
Cement	265,935 "	1935 " 1946 1,937,175 "

Minerals known but not worked included phosphates, bituminous limestone, manganese, copper, and small quantities of bitumen both pure and impregnating gravels. The phosphates unfortunately were of lower grade (43 to 56% tri-calcium phosphate as against 65 to 75%) than those of Trans-Jordan and were also physically less suitable. The bituminous limestones contained about 20% organic matter and yielded some 11-12% of oil on distillation. Extensive laboratory tests had been made by the Fuel Research Station and by others, but so far, no means of making commercial use of the rock had been found. Manganese occurred associated with Palaeozoic sandstones about 20 miles north of Akaba; tonnages had not been determined but 500,000 tons had been estimated in one place. Analyses showed 55 to 75% MnO_2 but associated with some copper. The copper occurrences consisted of impregnations in sandstone in and near the Wadi

Araba; although there was evidence of extensive working by the ancients there is little to suggest the presence of deposits workable under modern conditions although that might have been said about more than one mining field in its early stages.

Oil had so far not been discovered in Palestine, although some seepages were known on the eastern shores of the Dead Sea. Exploration was at present active although it had been delayed by the war and the unsettled state of the country. Interest centred on the coastal plain where structural ridges in the Quaternary and younger Tertiary beds might indicate deeper seated anticlines; on the striking but deeply eroded anticlinal structures in the Negeb; and on the southern end of the Dead Sea where seepages of bitumen were known and the salt mountain of Jebel Usdom suggested the existence of conditions favourable for the accumulation of oil.

Jernkontoret Celebrates its 200th Anniversary

"If all gold in the world disappeared our present culture would nevertheless be able to exist, but if all the steel in the world was removed, the very foundations of our material culture would go to pieces." With these words, Mr. Helge Silverstolpe, President of one of Sweden's most famous institutions, Jernkontoret (The Swedish Iron Masters' Association), opened his speech at the celebration of the 200th anniversary of the Association in the Stockholm City Hall recently. The event was attended by the Swedish Crown Prince, the Minister of Commerce and 600 guests from Sweden and abroad.

The Swedish Iron Masters' Association, which is an entirely private institution, of which all the Swedish firms in the steel and iron industry are members, was founded 200 years ago in order to create better marketing conditions for Swedish steel abroad. Sweden had for many centuries been one of the leading producers of iron in the world, and in the 18th century was responsible for about two-thirds of the world production. Nevertheless, the Swedish steel trade was not a particularly paying business as satisfactory prices were not obtained, partly owing to a less efficient sales organisation and partly to an inadequate credit capacity. Through establishing co-operation in the Jernkontoret and with support of the Bank of Sweden, the steel producers succeeded in overcoming these weaknesses and laid the foundations for a world-wide Swedish export of high-grade iron and steel, which is still to-day one of the country's foremost sources of income.

Gradually the Jernkontoret dropped its commercial interests, and it became its foremost task to promote scientific and technical research in the field of iron and steel. The organisation established mining schools and trained instructors and engaged experts, who were entrusted with the task of developing new methods of operating blast furnaces, etc. For instance, the mining dictionary and other instructional literature, written by the Association's first "Chief Smelting Master," Sven Rinman, also called "the Father of Swedish Mining," became indispensable aids to every Swedish mining engineer during the 18th century.

A noteworthy feature of the celebrations was the distribution of the Association's medal for merit in silver to six foremen in the Swedish steel industry. This medal, which was instituted in 1822, has during the past 125 years only been awarded 31 times. The men honoured were: K. E. Eriksson, Hofors works, for independent inventions, G. Gutke, Fagersta works, for his contribution to the development of the company's high-grade steel, Gösta Janssen, Demnarvet works, for contributions to the development of the Duplex method, G. Nordh, Storfors works, for contributions to the increase of production, O. A. Sköld, Sandvik works, for ideas for technical improvements, and K. A. Ohman, Söderfors works, for contributions to the development of the iron sponge method. All the recipients of medals are veterans who have been with their companies for 40 or 50 years and are all of old "steel" families, where the trade has gone from father to son for generations.

New Metallurgical Institute

In connection with the anniversary of the Iron Masters' Association the new Metallographic Institute in Stockholm was inaugurated by the Swedish Crown Prince. It is situated in the neighbourhood of the Stockholm University of Technology, where in recent years a whole series of modern research institutions has been established by private Swedish industry and the Government in collaboration. Among the many interesting devices, demonstrated at the Institute was a furnace capable of a temperature of 3,000°C., a temperature that is so high that a piece of steel placed in this furnace completely evaporates in two minutes. A crystal that produces sound waves with such a high frequency that the waves X-ray on a screen the object to be investigated and thereby reveal any possible defects was another notable detail in the scientific equipment, demonstrated to the 200 experts attending the inaugural ceremony.

A few weeks before the celebration the British Iron and Steel Institute, it will be remembered, awarded the Bessemer Gold Medal to the technical director of the Swedish Iron Masters' Association, Dr. Magnus Tiger-schiöld, in recognition of prominent scientific achievements.

Electropolishing Silver-Plated Parts in Cyanide Solutions

By Daniel Gray and S. E. Eaton

ELECTROPOLISHING of silver-plated articles has been adopted at the works of Oneida Ltd., instead of the traditional method of hand buffing. The method is clean, fast and low in cost compared with the hand buffing method.

As many as 72 pieces are polished at a time. Routine analysis of the electropolishing solution and an occasional setting of a voltmeter comprise the man-power involved. With electropolishing, it is possible to secure as high a lustre by the removal of 2% of the silver deposit as would be possible by removing 5-10% by hand buffing. This results in improvement of the finished article.

Electropolishing is the reverse of electroplating. In plating, the work is made the cathode (negative) and metal is deposited. In electropolishing, the work is made the anode (positive) and metal is removed. The method is relatively new and development in the past ten years has been rapid, particularly for stainless steel.

The process described in this article employs an alkaline cyanide solution. It was found that there are several modifications of the process, each of which has its own best application. The modification in use by Oneida, Ltd. for nearly a year and a half is well suited to electrodeposits up to about 0.002 in. This involves a short electropolishing cycle after the plating is complete.

At Oneida, Ltd., spoons, forks, and other articles are mounted in plating racks and plated in a typical cyanide bath. The racks are lifted automatically from the plating bath. They then pass over a drip-pan, following which they go into the electropolishing bath without intermediate rinsing.

The details of the process are simple. The solution itself is essentially a silver plating bath. The composition is roughly:

Silver: 4-6 oz. Troy per gal.
Potassium cyanide: 4-5 oz. Avoir. per gal.
Potassium carbonate: 6-8 oz. per gal.

About 5 volts d.c. potential at the source is applied, with the work to be polished used as the anode. The voltage across the cell itself varies with the area of the work to be polished. The cathodes are bars of silver. Although the cathode area is not critical

it should be large enough so that efficient deposition of silver may occur. A ratio of 1:2, anode to cathode is desirable. Incidentally, the silver removed is here recovered as pure metal. The saving in refining charges, as compared to the cost of recovering silver from buffing dust is considerable. The current required is 12-25 amps. per sq. ft. The polishing time is 15-18 seconds depending on the speed at which the machine is run. While being polished the work is moved by a screw conveyor for a distance of about 10 in. The full lustre is not apparent until the work is dry.

The preceding example describes the process as used on one particular machine. Other polishing machines vary in some details, such as solution composition, current density and time of treatment. For instance, on two machines there is no drip-pan. The work goes directly from the plating

bath into the electropolishing unit. The drag-in of plating solution on the surface of the work is considerable and it is necessary to adjust operating conditions so that a polishing solution compatible with the plating bath can be used. The point is that the process can be varied to suit conditions and obtain good results.

The great flexibility of this process may be ascribed to the fact that the factors of control are known, measurable and inter-dependent. These are: solution composition, voltage (or current), agitation, time and temperature. As cyanide content or temperature increases, more current is necessary. As carbonate content increases current demand is decreased. By varying one or more factors it is possible to produce a mirror finish in from 4-60 seconds. Obviously any desired amount of silver may be removed. The current efficiency of both cathode and anode is nearly 100%. The principal cause of variation in the electropolishing bath is drag-in on work. Since the viscosity of the polishing bath is low, the drag-out loss is not important. The solution is easily maintained by analysis and additions.

Aluminium Bearings

By M. Goret

WORK on the development of light anti-friction alloys in France was accelerated by the shortage of the constituents (copper, tin, lead) of the commonly used bearing alloys. A series of experiments was undertaken by the Compagnie Alais, Froges et Camargue and the Aluminium Français to obtain alloys with a low copper tin and lead content which would give a high standard of performance. The experimental bearings were tested on a specially designed machine, the construction and operation of which are described.

Two aluminium alloys were developed commercially as a result of the investigations: Coussinal A (Sn 3%, Pb 2%, Sb 3%) and Coussinal C (Sn 4%, Cu 4%, Mg. 3%, Mn 1%). Coussinal A is intended to serve as a lining, and can be applied to shells of steel, copper, copper alloys or light alloys. Coussinal C serves to replace bearing alloys. Both alloys have been used successfully for bearings for shafts and cranks of piston compressors, rings for cam-shafts and bearings for

electric motors. General conclusions derived from the tests were that light alloy bearings require a greater clearance, (80 to 125 μ for a diameter of 40 mm.) and copious lubrication: diamond finishing of surfaces is not thought to be more satisfactory than careful machining.

During the war, the Société Algérienne du Metal Palium replaced copper base bearing alloys by a series of aluminium alloys. Amongst these, Palium Da (Sn 1%, Cu 4%, Mg 0.8%, Zn 22%, Pb 4%, Mn 0.3% and Fe less than 1%) of Brinell hardness 120 and Palium Z (Sn 2.6%, Cu 4.5%, Mg 0.6%, Zn 0.3%, Pb 4%, Mn 0.3%) of Brinell hardness 70, showed good properties. The testing of these alloys is detailed and uses to which they have been put are referred to.

Experimental work was carried out by P. Elicin and J. Cournot on binary aluminium alloys containing nickel (8, 10, 11, 12, 14, 16%); manganese (5, 6.5, 8%); antimony (12%); molybdenum (6%); cobalt (6, 8, 10%); iron (7.5, 10%). Research was also undertaken on aluminium-nickel-chromium alloys.

Revue de l'Aluminium, 1947, No. 133, 155-169.
Abstract from *Light Metals Review*, VI, No. 19, 393.

From *Materials and Methods*, 1947, 27 78.

funds do not run to this and the conditions are reasonably normal, the balance, housed in a glass case, may be set up in the laboratory. However, for a large organisation,

allowed for each balance, and 4 ft. for the combustion apparatus. In addition, room is required for an ordinary analytical balance, and for a small preparation table

IT is distressing, and indeed perturbing, to read of the further restrictions which will be imposed, as a result of the crisis, on the importation of books from America. Without discussing these in detail, the broad results will be that the number of books will be fewer, they will be more difficult to obtain, and the delay will be considerably greater. We would naturally like to see this country independent of America in the matter of books. Scientifically, of course, independence is only a relative term, since no country can afford to be ignorant of what other countries are writing about science. Independence would simply imply the ready availability of more advanced text books and journals, coupled with a sufficient supply of British written and produced basic text books. With the shortage of paper, and the lack of time of potential writers in the past decade, there is, as everyone knows, not only a dearth of good text books, but a dearth of text books of any quality whatsoever. The problem of recommending text books to students, for example, has for some years been a harrassing race to fit the type of book required to the type of book available at any particular moment, the latter condition being liable to alter with chameleon-like rapidity. If to this is to be added a major difficulty in obtaining the fundamental information which can only be found in the writings of working scientists, the lot of the research man, already in many ways unenviable, is going to become overloaded with restraints.

The Microchemical Laboratory—— Its Design and Equipment

By G. Ingram

The importance of microchemical methods of analysis has been repeatedly stressed on many previous occasions in these columns devoted entirely to microchemistry. Of equal importance is the place where this work is carried out. The following, the result of many years experience gained in designing and installing such laboratories, is offered as guidance, for those about to prove for themselves the merits of microchemistry.

IN its infancy microchemistry on the whole required very little apparatus and space for carrying out the various techniques then developed. To-day however, the picture is entirely different. Such rapid advances have been made in adapting micro methods to ordinary analytical purposes, that a well planned laboratory is needed for the work.

The design and construction of such a laboratory is greatly influenced by the kind of analysis performed, and by conditions which are likely to affect the attainment of accurate working. This particularly applies to the micro-balance. Naturally, such a factor does not apply in the case of qualitative analysis, where any general laboratory will suffice, provided certain conditions relating to cleanliness, etc., are adhered to.

Broadly speaking, there are three types of microchemical laboratories—the research, industrial and teaching institute laboratory. Although each may have an entirely different duty to perform, the selection of a

room as a microchemical laboratory for any one of them must be made with care, bearing in mind the following points.

Firstly, a room should be selected which is on the ground floor with windows facing north so that sunlight does not fall directly on to the balances. The size of the laboratory will of necessity depend on the amount of bench space required for the permanently erected apparatus. For an example, this will be considerable for the organic micro-laboratory.

Secondly, it must be as far away from sources of vibration as possible. This is an important point with regard to the selection of the permanent site for the micro-balance.

Thirdly, the room must be far removed from sources of dust and fumes.

If the size of the laboratory chosen permits of it, or there is a smaller one leading off, the provision of a separate balance room is an added advantage. If

The Combustion Room

It is convenient to combine the combustion units, i.e. for nitrogen, halogen, sulphur and perhaps oxygen,

furnace is to be recommended as this may be controlled by a time-switch, so that tubes may be heated during the night and be sufficiently cooled in the morning for

funds do not run to this and the conditions are reasonably normal, the balance, housed in a glass case, may be set up in the laboratory. However, for a large organisation, the provision of a separate room is really worth-while considering for the following reasons. Careful weighing is uninterrupted by disturbances from other workers in the laboratory. Better control of temperature, humidity and protection from draughts is possible, especially if two or more balances are to be installed.

By employing (in the case of the organic laboratory) electrically heated furnaces for the carbon and hydrogen apparatus, these may be set up in the balance room on a bench opposite the balance table. This practice has many advantages: the operator has less walking to and fro with absorption tubes, which also are maintained at the same temperature as the balance room. This system has been used by myself for a number of years with complete satisfaction. Finally, such a scheme allows the smooth working of a set programme to be carried out by several operatives.

It is difficult to set a standard for the size of the laboratory. Much will depend, as has already been stated, on the amount of bench space required and on the types of analyses to be performed. In the research laboratory dealing with organic analysis space will be required for carbon and hydrogen, nitrogen, halogen and sulphur estimation apparatus, and for the various group determinations. On the other hand, in the industrial laboratory, the type of analyses carried out may apply to metallurgical work. In this instance, most of the procedures will probably be colorimetric, employing a filtration technique perhaps for the separation of individual ions. Such work will only require half the space required in the former. For teaching purposes, it is sometimes only possible, owing to the lack of a micro-balance, to teach the fundamentals of microchemistry. Or if one is available only weighing technique followed by a simple manipulative exercise is carried out. Either of these requires a reasonably small amount of working space unless a large number of pupils are to be taught. On the other hand, where the more difficult techniques are to be taught such as carbon and hydrogen, more space is necessary so that each individual, or pair, has a balance and apparatus.

From experience, the average size for a micro laboratory for general research material, including the balance room, is about 750 square feet. This will allow for sufficient bench space for all necessary apparatus required by a large organisation. The layout of such a laboratory is shown in plan in Fig. 1. Naturally, for smaller organisations or laboratories dealing with different types of material, adjustment can be made to suit individual requirements. As illustrated, the laboratory has been divided into four separate sections, a scheme much favoured in America¹ because of its advantages. Each of these sections will be dealt with in detail below.

The Balance Room

The balance room, A, should be sufficiently large to allow freedom of movement when operatives are at the balances. Two benches are required, 2½ ft. wide, consisting of slate slabs at least 1½ in. thick. The length of each will, of course, depend on the number of balances and apparatus to be used. At the most, 3 ft. should be

allowed for each balance, and 4 ft. for the combustion apparatus. In addition, room is required for an ordinary analytical balance, and for a small preparation table 3 × 2½ ft. The distance between each bench must not be less than 4 ft. As the balances should not be placed in front of a window, the room must be arranged so that the latter is on the side or behind the work bench. Further, they must not be placed near any form of lighting and heating arrangements.

To minimise vibration effects, the balance table is built away from the wall, with blocks of hard wood, 3 in. square, inserted crosswise between the supports and bench top. Layers of sheet lead are also placed either side of the hard-wood blocks. In this way vibrations are completely deadened.

To hold the various cleaning spills, forceps, spatulas, etc., small drawers are fixed below each balance site. On the wall above, 2 ft. from the bench top, a glass fronted cupboard with sliding doors serves to store micro-desiccators, copper-blocks, filter tubes and other small pieces of apparatus which are not in immediate use.

Illumination for the balances is provided by symmetrically placed lights fixed at least 4 ft. above each balance. In addition, power plugs are needed, or a transformer is required to supply a small voltage current for balances that employ a

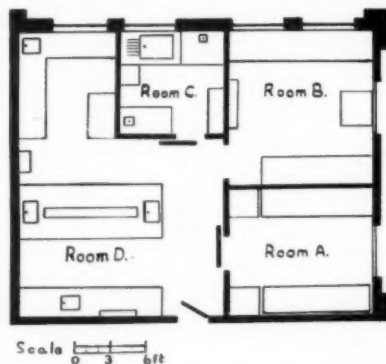


Fig. 1.—The layout of a microchemical laboratory.

prismatic reflecting device for the pointer scale.

The combustion bench fits flush with the wall and is provided with the necessary power plugs and table lamps for illumination of the apparatus. Suitable storage space for spare combustion tubes, absorption tubes and the like is provided for by a cupboard and nest of drawers fitted underneath the bench at either end. Oxygen for combustion purposes is conveniently supplied on tap from a cylinder situated in the main combustion room. This oxygen line should extend round that part of the laboratory where it is likely to be required at any time. Copper tubing is used throughout to supply the gas to the various points. Fine adjustment is obtained with needle-valve taps. Air for Pregl combustion apparatus may also be drawn from a compressed air line provided it is free or comparatively free from oil vapour. By using a preheater in the combustion train this difficulty is overcome.

Entrance to the balance room is provided by a sliding door situated so that draughts are avoided.

The preparation table is used to fill absorption tubes and combustion tubes, and for any other manipulative work in connection with preparation of the sample for analysis. Drawers are fixed underneath for the storage of samples, and shelves are fixed to the wall above to accommodate the various bottles containing absorbents and fillings for the combustion tubes.

¹ H. K. Alber and J. Hunsd. The Microchemical Laboratory of the Biochemical Research Foundation, *J. Frank in Institute*, 1937, 224, No. 6.

The Combustion Room

It is convenient to combine the combustion units, i.e., for nitrogen, halogen, sulphur and perhaps oxygen, together in one section. The position of Room B (12×12 ft.), (Fig. 1) is ideal for this purpose owing to the fact that only an oxygen and gas supply are needed. Good ventilation is essential owing to the large amount of heat given off from the furnaces. By using well-lagged electrically heated furnaces, the temperature in the room is reduced considerably.

The two work benches, one 12×3 ft. and the other $10 \times 2\frac{1}{2}$ ft. for the nitrogen apparatus, consist of slate slab or other heat resisting material. Cupboard units should be fitted at either end for storage of apparatus and individual drawers in the centre for working tools. Adequate gas taps and electric power points should be provided at intervals of 3 ft. between each, together with needle valve taps for the oxygen supply, at intervals of 4 ft. Glass shelves are also needed for the various reagent bottles. A small table for working out results and a glass fronted cupboard completes the fitments for this room.

Illumination for the room is provided by two 100 w. lamps, whilst individual table lamps are required where the various apparatus is to be set up.

The Preparation Room

This section of the laboratory, Room C (9×9 ft.) is reserved for preparative work and decomposition of samples which require a fume cupboard to remove corrosive fumes. This section should also be used for cleaning and washing apparatus. So that combustion tubes and burettes can be cleaned easily, a large sink should be installed which should have a rubber sheet at its bottom to avoid accidental breakages. A suitable size sink for this purpose is one measuring $3 \times 2\frac{1}{2}$ ft. The fitments for it include a hot water heater, a water suction pump to facilitate the rinsing of pipettes, etc., and a distilled water tank fitted above, with a long glass lead into the sink for rinsing purposes. An oven for drying apparatus should be placed nearby, together with a compressed hot air drier for pipettes, etc.

The fume cupboard should be large enough to accommodate an electric water bath, hot plate and Kjeldahl digestion stand, and leave sufficient room to carry out the various wet oxidation operations. A small sink 7×7 in. is required for drainage of water, and for fitting two water suction pumps: one for the Kjeldahl digestion apparatus and the other for miscellaneous use. For convenience, water taps for condensers and the water bath, a compressed air line, if this is installed in the building, and an oxygen tap should be placed to the front of the fume cupboard. Such a system eliminates reaching over apparatus in the fume cupboard to get to the back where most supply lines are usually fixed. Likewise power plugs are fitted on to a panel outside on the front of the fume cupboard. Glass shelves are fixed to the back wall for the acid and reagent bottles. Finally, a shadowless and uniform illumination is an added advantage for the fume cupboard, which is provided by inserting strip lighting inside.

The Carius bomb furnace is best installed underneath the fume cupboard on the side nearest to the partition wall. As a precaution, should the bomb tubes explode at any time, it is entirely enclosed, with a door facing the front for inserting the tubes. An electrically heated

furnace is to be recommended as this may be controlled by a time-switch, so that tubes may be heated during the night and be sufficiently cooled in the morning for opening.

Two further work tables are required in the preparation room, one for glass blowing, and the other for the preparation of solutions and reagents. The latter, shown in the diagram, to the left of the door, needs a small sink, 7×7 in. for drainage of water and water pumps, a gas supply, and power plugs for an electric water bath and hot plate. Ordinary laboratory glass ware is stored in the cupboard fitted underneath.

The installations of the blow-pipe table should include both oxygen and a compressed air line, and a drawer for the various glass blowing tools required. A 100 w. bulb is sufficient for illumination of the room, with individual 60 w. bulbs over the two work benches. Finally for convenience, the entrance should be closed by a sliding door.

The Main Laboratory

This section of the laboratory should be reserved for the group determinations and other special techniques, using perhaps the instruments developed for micro-chemistry. The suggested layout for the section is clearly shown in the diagram.

The bench (12×3 ft.) where all filtrations are carried out should be situated as near to the balance room as is practical. A sink for drainage of water and the installation of water pumps is required, which is placed 4 ft. from one end. The various heating blocks and apparatus for drying substances *in vacuo* is fitted up in this smaller part of the bench, whilst the remainder is used for filtration purposes. A glass fronted cupboard, 8 in. deep, with sliding doors, should be fixed to the wall at the back of the bench for microfiltration apparatus and wash bottles. Cupboard units underneath are required for the storage of ordinary filtration apparatus and beakers: whilst drawers serve for filter paper and other filtration apparatus such as filter-tubes, filter-sticks and beakers.

The high vacuum pump for the drying apparatus is best placed in a half cupboard unit next to the sink, together with the necessary traps for removing solvent. The vacuum line from the pump should pass up through the bench top at the back to a branch line for connection to the drying apparatus.

The installation of the suction points for the various filtrations is greatly facilitated if the building is equipped with a vacuum line. The outlets, four of which are usually sufficient, should be placed to the front of the bench through holes, so that the ends are flush with the top. The suction is controlled through fine needle valves fixed on to a panel in front of the bench.

The use of a suction plate as described by Alber and Harand², has proved of immense value with the use of specially designed equipment of the bell jar type. A sheet of glass plate, 20×20 in., ground on the top surface, is let in flush with bench top. Gas and three electric power points complete the requirements of the bench.

The wide bench (12×6 ft.) fitted with sinks at both ends and, separated down the centre, should be reserved for the various apparatus required for group estimations. The special features of this bench are the glass fronted sliding doors for the shelves, to keep the many bottles

² *Ibid.*, 744.

of reagents free from dust and contamination; the silica-gel drying cabinet for storing the Zerewitinoff and other apparatus which, after drying in the oven, must be kept so; and the nitrogen gas line drawn from a cylinder and supplied to the bench by the same system as for the oxygen supply. The nitrogen is required for the acetyl, methoxyl and active hydrogen estimation. The bench is also supplied with the necessary services such as water, gas and electric power points.

Cupboard units, including drawers are required for storing the apparatus in; these are fitted under the bench at either end. The space left in the centre of the bench is required for the silica-gel cabinet one side and for a drying oven the other.

The remaining bench space shown in the diagram is required for such instruments as the "Spekker" Absorptiometer, a centrifuge, and electrometric titration and micro-electro-analysis apparatus, if these are to be

used. An ordinary balance should also be set up on a table against the wall, as shown in the diagram.

The smaller table, 4 x 3 ft., is fitted up as the titration bench, in a manner as described by Alber and Harand³. The equipment includes a ground glass plate illuminated underneath by bulbs controlled with a sliding resistance in order to increase or decrease the brightness. By using UV-light it is also possible to carry out titrations using fluorescent indicators. Standard solutions should be stored in the cupboard under the table. Glass shelves fixed to the wall at the back are needed for the indicator bottles. Other apparatus needed for titration work such as pipettes, burettes and flasks are stored in drawers and cupboards under the bench opposite.

Illumination of this section is afforded by three 100 w. bulbs, with individual overhead 60 w. bulbs for the benches.

3 *Ibid.*, 746.

Microchemistry Group Meeting

A JOINT meeting of the Microchemistry and Physical Methods Groups of the Society of Public Analysts and Other Analytical Chemists was held in Cambridge on Friday, September 26th. Following visits to the Colloid Science Department and the Radiochemistry Laboratory, four papers on topics of interest to both Groups were read under the chairmanship of Mr. R. C. Chirnside, F.R.I.C., of the Physical Methods Group.

Molecular Weight Determination

Dr. C. L. Wilson, M.Sc., F.R.I.C., discussing "Micro-methods for Molecular Weight Determination," pointed out that while numerous methods have been proposed for the determination of this physical constant, it is difficult to assess the relative merits of the methods, and a critical examination of methods is in progress. Molecular weight can be derived from the measurement of properties of dilute solutions—the most usual of these being the elevation of the boiling point, the depression of the freezing point, and the lowering of the vapour pressure or some phenomenon related to it—or from vapour density determinations.

Ebullioscopic methods may derive from the classical method, using a smaller edition of the usual Beckmann thermometer, or from methods which make use of a differential water thermometer, and which employ either flame or electrical heating. While classical cryoscopic methods have been adapted to small-scale working by a few investigators, the principal advance in this branch has been the well-known camphor method of Rast. Numerous other solvents with a high cryoscopic constant have also been utilised, and various melting point baths have been constructed with special reference to cryoscopic methods.

The Barger method utilises the difference in vapour pressure between non-isotonic solutions, so that comparison between standard solutions and an unknown enables a worker to arrive at the molecular concentration of the unknown. This method has been modified by Rast, and many other workers have proposed methods of isothermal distillation employing the same principle, which can be applied on a range of scales, and which

have the added advantage that they permit ready recovery of the sample.

A number of vapour density determinations are essentially based on the classical method of Victor Meyer, where the volume of vapour is read. Alternatively, the vapour may expel mercury, which is weighed, the weight being subsequently transformed into terms of volume. Finally, instead of determination of volume, the temperature or pressure necessary to maintain the vapour at a fixed volume may be determined.

Turbidimetry in Soils

Dr. J. Tinsley, B.Sc., F.R.I.C., dealt with "Turbidimetric Methods Used in Agricultural Analysis." Nephelometric methods were applied to soil analysis and to the chemical analysis of plant tissues as early as 1906. The alternative technique of spectrographic analysis suffers from the drawback that the apparatus is not always readily available. Consequently turbidimetric methods for soils are often more convenient, and are sometimes more useful.

The ions of analytical importance in soils are nitrate, phosphate, sulphate, chloride, borate, potassium, sodium, calcium, magnesium, manganese, iron, copper and zinc. In soils these may be present in any condition from highly soluble to relatively insoluble. The soluble, or "available" ions may be obtained readily by ion-exchange methods. In so-called rapid methods of analysis, the soil is extracted for a short period, and aliquots of the extract are taken for analysis. Potassium, calcium, chloride and sulphate lend themselves to turbidimetric analysis. Of these, most attention has been paid to the determination of potassium. Early methods, using sodium cobaltinitrite as reagent, were relatively crude, but the advent of photoelectric measurement, preferably by transmission rather than by reflection, has made it possible to achieve a reliable determination.

Potentiometric Methods

"Microchemical Applications of Potentiometric Methods" were described by Mr. J. T. Stock, M.Sc., F.R.I.C., who confined his remarks largely to methods

involving the handling of small samples, rather than those requiring the determination of small amounts in large samples. In this field one may require to measure the actual potential produced, as in the micro-determination of pH. Alternatively, the need may be to follow a change in potential, as in a titration. Small-scale potentiometric determinations often show advantages when compared with methods which require classical techniques such as the use of coloured indicators, where a number of special problems arise on reducing the scale of the experiment.

Adequate stirring of the medium is necessary, and this has been achieved either by the orthodox use of gas-bubbles or mechanical stirrers, or by such procedures as rotation or vibration of the vessel, the electrodes remaining fixed. Vibration has been applied to titrations on the drop-scale, so that, for example, a few thousandths of a microgram of silver has been successfully determined.

The electrodes require to be specially designed. In one example, an electrode dips into the vessel, while the second is incorporated in the burette tip. Dipping the tip of the burette into the liquid serves a double function, in that it makes the circuit, eliminating the necessity for a tapping key, and at the same time allows additional liquid to flow into the receiver from the burette.

Micro-glass electrodes have been developed which can be used as stirrers, or even as containing vessels for the liquid being titrated. Finally, measuring instruments have been improved considerably by the application of electronic devices, so as to render the determination of end points considerably more certain.

Reviews of Current Literature

Symposium on Metallurgy of Steel Welding

THIS admirably produced book contains all the papers and discussions of a series of meetings organised by the British Welding Research Association, the objective of which was to provide means of promoting an exchange of views on the work and programmes of the Association's various Committees. The Symposium was so successful that, in view of the importance of the subject and the wide range of the papers presented, the Association was justified in having them published, together with the discussions, in book form.

In his opening statement, inaugurating the Symposium Sir William J. Larke, K.B.E., President of the Association, pointed out that the series of meetings which made up the Symposium served to make those interested in the application of welding fully aware of the work in hand and the results obtained. It gave an opportunity to make authoritative statements on the work and its results, and would give rise to comments, suggestions and criticisms which would stimulate further effort and in some cases suggest additional avenues of investigation.

The book includes some of the most comprehensive papers produced in recent years on welding science. Notable among these were "Constitution of Weld Metal" by W. Andrews, "A Preliminary Investigation of the Constitution of Mild-Steel Arc-Weld Deposits" by H. A. Sloman, T. E. Rooney and T. H. Schofield, and "An Analytical Examination of Weld Deposits from Commercial Mild Steel Electrodes to Specification B.S.S. 639A, and the Manufacture of Artificial Weld

Micro-analysis by X-rays

Mr. H. P. Rooksby, B.Sc., F.Inst.P., spoke on "Micro-analysis Using X-ray Diffraction Technique." Even by conventional X-ray methods only a very small amount of material—a fragment of crystal weighing a few micrograms or a rod moulded from powder and weighing about half a milligram—will give a satisfactory X-ray pattern. The normal methods are limited by the difficulty of mounting small fragments in a suitable orientation, or of moulding the powders into convenient rods.

By applying a different type of camera, even smaller amounts may be investigated. A powder is smeared on a film of tissue paper which acts as a support, and this is inserted in the specially designed camera. As little as one-hundredth of a milligram of powder will give a good X-ray photograph, and in favourable conditions it is probably possible to work with smaller samples. When it is necessary to investigate a thin film which may not be removed from the base support, the reflection technique, usually in conjunction with a small rocking motion of the sample, is applied.

By these methods foreign films in vacuum devices and pumping systems have been successfully analysed in conditions where chemical or spectrographic methods would fail—e.g., where it is necessary to distinguish between metal and oxide or other compound. Discolourations in cathode films, and on the surface of metal films after heat-treatment, have likewise been identified. Quantitative results are possible in mixtures such as zinc-cadmium sulphides, or strontium-barium carbonates.

Metal" by G. L. Hopkin. These papers gave rise to an interesting discussion.

Important contributions to the Symposium were made by Dr. L. Reeve, whose papers included "The Relation between the Hydrogen Content of Weld Metal and its Oxygen Content," "Influence of Sulphur and Phosphorus on Weldability of Mild Steel" and a note on "Cracking of Welded Gas Mains." Drs. Wheeler and Kondic submitted "Effect of Initial Heating Temperature on the Mechanical Properties of an Air-Hardened Ni-Cr-Mo Steel," giving an account of investigations at Birmingham University and presenting for the first time data on transformation products formed after quenching from abnormally high temperatures.

An interesting paper by P. K. Gledhill outlined "An Apparatus for the Determination of the Viscosity of Welding Slags" and gave the results of preliminary investigations. Another important contribution was "Electro-Physics of the Welding Arc" by Dr. L. H. Orton.

There is much information in this book which is not available elsewhere and it can be regarded as a useful means of presenting the results of modern metallurgical research in relation to arc welding. In size, the book is 11 in. × 8½ in., it contains 104 pages and is well illustrated.

Published by British Welding Research Association, 29, Park Crescent, London, W.1. Price 10/-.

Grundlagen der Eisengewinnung

THIS book has been compiled for students and all those who wish to acquire an insight into the principles of iron and steel manufacture. The various processes

for making iron and steel are first of all outlined briefly and diagrammatically. Afterwards, the author proceeds to show how the physical chemical equations, much used in the subject, are derived, i.e., the law of mass action, partition co-efficient, equilibrium constants and phase rule principles.

Commencing with the physical properties of iron, oxygen and carbon, the iron-oxygen and the iron-carbon equilibrium diagrams are shown and discussed. The important carbon-oxygen gas equilibrium relationships are clearly shown and the reader is then equipped to study the reduction of iron oxides, i.e., ore, by carbon monoxide, hydrogen, methane and solid carbon. Equations based on physical chemical principles and intimately connected with the production of iron and steel are put forward and explained. From this point of view, the book gradually turns to plant operational work and begins by studying the reducibility of metals and non-metals in the blast furnace.

The theoretical appreciation of the formation of blast furnace slags is explained by concise equilibrium diagrams. Historical and economic reviews show the world distribution of coal, oil, water-power, also iron ore, and there is also a brief review on other iron and steel works raw materials such as limestone, fluorspar, etc. This leads on to smelting where the salient features of processes used in ore reduction by coke, hydrogen, etc., to spongy iron are illustrated and discussed. The economic advantages of direct reduction make an interesting topic.

Metal Powder Report

READERS interested in powder metallurgy are invited to apply to Powder Metallurgy Ltd., Commonwealth House, 1-19, New Oxford Street, W.C.1, for a specimen copy of the "Metal Powder Report." This 16-page monthly abstracts journal is edited by Dr. W. D. Jones and Mr. R. A. Hetzig. The September issue contains full summaries of recent B.I.O.S. reports, British, French, U.S. and Canadian patents as well as a number of important scientific papers on the manufacture and uses of metal powders.

The "Metal Powder Report" has been circulated privately for the past year and now enters Vol. 2. The subscription rate is £3 7s. 6d. per annum, post free.

Philips' Technical Review

THE latest issue of the above Review deals with four widely-differing scientific subjects. Probably the most interesting is that concerned with certain problems encountered in photographic reproduction, particularly in respect of sound films. The authors of this article, Messrs. C. J. Dippel and K. J. Keuning, state that numerous drawbacks associated with the problem of copying sound film have been overcome by a new method developed during the war by research workers in the Philips laboratories. In this new system, the picture carrier is not an emulsion but a non-granular homogeneous solution, which means that the resolving power of the film itself is raised considerably. It is stated that the applications of this new development will be discussed in a later issue. Another contribution, that on "Electromagnetic Cavity Resonators," deals with the forms of oscillation of some electromagnetic cavity resonators to be employed in the ultra short

Blast furnaces come next and the principles of ore reduction, slag formation and basicity ratios are discussed on practical lines, by calculations based on the composition of the materials passing through the blast furnace. The very important thermal considerations of blast furnace practice are also treated. The production of pig iron in the electric shaft furnace and smelting generally by revolving furnaces and synthetic processes are also illustrated and the economics of the processes calculated.

The book then leads on to puddling and hearth refining processes for refining pig iron into steel, the Bessemer and Thomas steels, and, of course, the Siemens-Martin open hearth process, Talbot tilting furnace and electric arc and induction furnaces are all described. The book closes with a note on the future trend of development and considers briefly the application of oxygen enriched air and the benefits to be accrued from same.

Of course, such a wide range of subjects is not dealt with in operational detail, but the metallurgical principles involved are clearly indicated with sufficient illustrations to enable the reader to appreciate the fundamentals of iron manufacture. The book makes for straightforward reading by the omission of all but the slenderest references to the source of much of the information given.

By Dr. Ing. Robert Durrer; (in German) published by A. Francke Ltd. Co., Berne, Switzerland; price S.fr.20.

wave range instead of the usual oscillatory circuits. Further articles include "The Practical Construction of Vibration free Mounting with Auxiliary Mass" and "A Remarkable Feature of Technical Fixed Dielectrics."

Copies of this issue (Vol. 9, No. 3) may be obtained from Publications Department, Philips Electrical Ltd., Century House, Shaftesbury Avenue, London, W.C.2. Single copies 2/- each, post free.

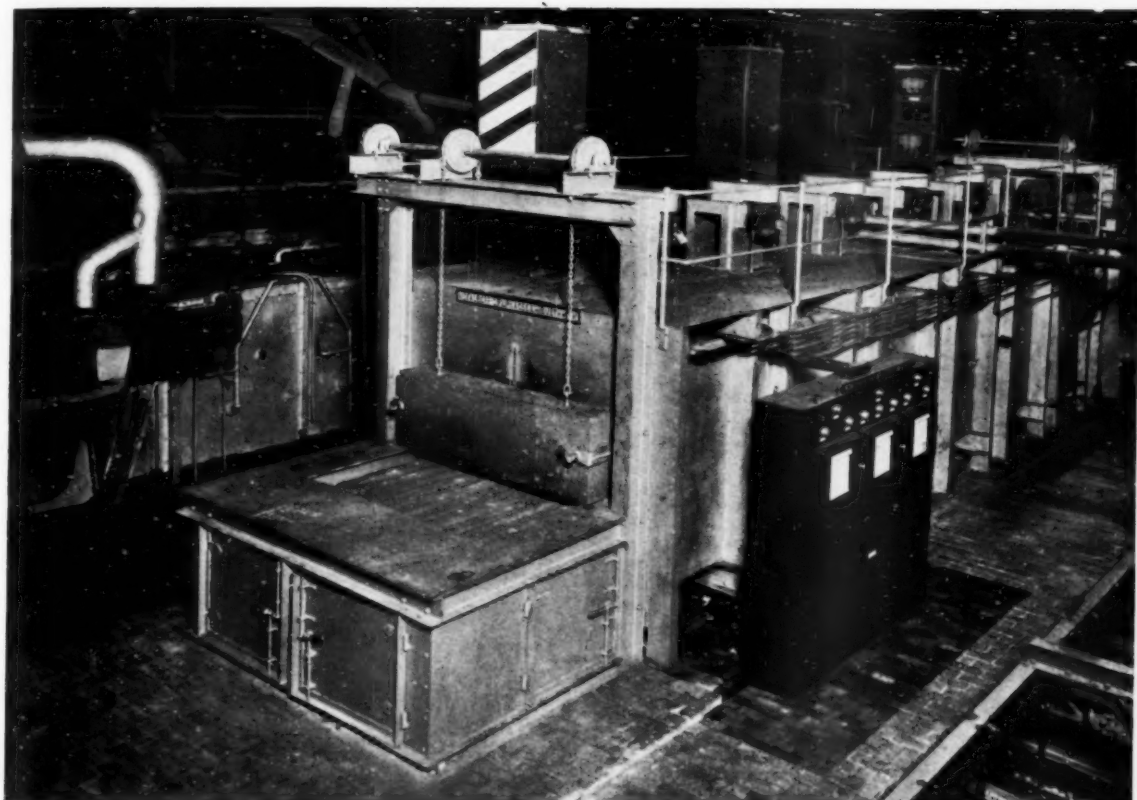
Steel Production Increased

STEEL production during September shows a substantial increase over September of last year and reached the highest production rate ever recorded for that particular month. Indeed, this rate of production is the highest for any month since March, 1943. The detailed statistics for pig iron and steel production are:—

PIG IRON.				
		1946		1947
		Weekly Average	Annual Rate	Weekly Average
1st Quarter	.. ..	145,500	7,560,000	134,400
2nd Quarter	.. ..	150,500	7,827,000	141,600
3rd Quarter	.. ..	146,600	7,622,000	146,700
August	.. ..	145,300	7,558,000	147,300
September	.. ..	147,300	7,660,000	150,100

STEEL INGOTS AND CASTINGS.				
		1946		1947
		Weekly Average	Annual Rate	Weekly Average
1st Quarter	.. ..	242,600	12,617,000	216,000
2nd Quarter	.. ..	232,100	13,111,000	244,100
3rd Quarter	.. ..	230,000	11,953,000	235,400
August	.. ..	225,900	11,747,000	234,200
September	.. ..	238,500	12,402,000	266,200

The continued maintenance of this high rate of steel production depends primarily on the implementation of the coke allocations and on the return to the steel works of all possible scrap supplies.



Photograph by permission of The Ford Motor Co. Ltd.

Continuous Tempering!



The Incandescent Group has many other interesting developments and you will find it well worth while to consult them on all Heating and Heat Treatment problems.

The illustration shows a Metaelectric Tempering Furnace designed to give an output of 1 ton per hour of forgings and stampings, at a temperature of 750°C. The furnace is continuous in operation, the conveyor being of the cast link type. Working dimensions are:—Heated length: 28 ft., width: 5 ft. 3 ins., height: 10 ins., rating 350 kilowatts. Uniformity of temperature is assured by zoning of the heating elements and by provision of independently driven air circulating fans mounted in the roof of the furnace. The furnace operates at high efficiency and low maintenance costs. Replaceable parts are easily accessible and the heating elements are so arranged as to facilitate rapid removal and replacement without danger to the operators. This furnace is one of many types designed to meet specific requirements.

METALECTRIC FURNACES LTD.

SMETHWICK - BIRMINGHAM Telephone: SMethwick 1561-2

A MEMBER OF THE INCANDESCENT GROUP

London Office: 16 GROSVENOR PLACE, LONDON, S.W.1

Telephone: SLOANE 7803 & 9818

OCTOBER, 1947

METALLURGIA



SUPER HOLFOS is produced by carefully controlled and perfected casting methods. Its physical characteristics—high compressive strength, high load carrying capacity and a low friction coefficient—give it particular suitability to special and general gear applications. The plant, layout and research facilities at the Holfos factory are developed to the very latest degree of modernity and are capable of producing a wide variety of bronze castings by the most efficient methods.



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